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The Effects of Equipment Age on Spare Part Costs

A Study of M1 Tanks

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Preface

During its transition to the Future Force, the Army will continue to utilize its existing weapon systems for an extended period. Army personnel have argued that repair costs are increasing as equipment ages, putting a strain on maintenance budgets. However, quantitative relationships have not been established between equipment age and maintenance costs, making associated budget requests difficult to justify.

This report focuses on M1 Abrams tanks and discusses some of the mitigating factors that likely dampen any age-cost relationship and other limitations that hinder the quantification of a potential age-cost relationship. Given these factors, it examines what the available data show about the effects of equipment age on spare part costs.

This research was conducted for an ongoing project titled "Equipment Readiness Measurement and Drivers." This research is a companion piece to the RAND Arroyo Center report by Eric Peltz et al., *The Effects of Equipment Age on Mission Critical Failure Rates: A Study of M1 Tanks (www.rand.org/publications/MR/MR1789)*, that investigated the effects of age on mission critical failures, a key component of readiness. Both reports should be of interest to resource planners and logistics analysts.

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Summary

M1 Abrams Tank Fleet Aging Is Prompting Concerns About Maintenance Costs

As the Army transitions to the Future Force, it will continue to rely on existing weapon systems, such as the M1 Abrams tank, until the Future Combat Systems (FCS) and companion systems are fully fielded. This has prompted concerns by Army officials who have argued that the increasing age of the Army's fleets is leading to lower readiness and higher costs. As a result, the Army has initiated programs such as recapitalization to selectively rebuild and upgrade systems.

Budget justifications for such programs have sometimes been difficult, because empirical studies have not demonstrated a convincing relationship between age and maintenance costs. For example, a recent RAND Arroyo Center study of M1 tanks found that although increased equipment age is associated with increased mission critical failures and thus likely affects readiness, little to no age effect is apparent among the high-cost parts that dominate M1 spare part expenditures.[1] Similarly, a recent Congressional Budget Office (CBO) study found no evidence of a link between M1 tank age and operating costs.[2]

However, such cost studies are hampered by a lack of data to effectively account for all maintenance costs. In this report, we discuss the data limitations as well as practices and behaviors within Army units that can obscure the effects

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[1] Eric Peltz et al., *The Effects of Equipment Age on Mission Critical Failure Rates: A Study of M1 Tanks*, Santa Monica, CA: RAND Corporation, MR-1789-A, 2004, p. 27 (age-failure relationship) and p. 48 (high-cost parts).

[2] Congressional Budget Office, *The Effects of Aging on the Costs of Operating and Maintaining Military Equipment*, August 2001, p. 17.

of age on maintenance costs. Then we examine what the available data show about M1 age and spare part costs, and we also analyze whether part turn-in practices might obscure the effects of age on costs. We conclude with recommendations for improving the Army's data capture and business processes to enable better fleet analysis and management.

Mitigating Factors Can Hamper Studies of an Age-Cost Relationship

Cost Data Are Lacking in Key Areas

A critical factor hampering studies of an age-cost relationship is the lack of detailed maintenance-related data for all relevant Army budget accounts. By one estimate, field labor accounts for over half of the Army's cost of maintaining equipment (including depot maintenance).[3] However, age versus equipment operating cost studies have typically focused on the spare parts portion of Operation and Maintenance (O&M) accounts, because good maintenance labor hour data are lacking. The lack of labor data, as well as the failure to maintain life cycle part and labor histories at the end item level, makes it difficult to apply standard "economic useful life" models to estimate cost-effective replacement schedules. (Because data on maintenance costs for individual tanks are not available, this study relies on estimates of spare part costs at the brigade level.)

Spare Parts Budgeting Process Likely Dampens Spare Part Spending

Army budget analysts use a moving average of three years of spare part demand history, updated with current prices and credits, to determine a cost-per-mile factor for each end item variant. The factor is then multiplied by the number of each end item and the forecasted operating tempo (OPTEMPO) to determine the O&M spare parts budget allocation for each major command (MACOM), which distributes the funds to its subordinate units.

The budget determination process has no trend component to account for projected increases in part demands. Because a unit cannot spend beyond its budget, under normal circumstances, across all end items to be supported, its

_____

[3] Eric Peltz, *Equipment Sustainment Requirements for the Transforming Army*, Santa Monica, CA: RAND Corporation, MR-1577-A, 2003, p. 14.

aggregate spares spending cannot "float" to meet increased needs. Nor does the Army systematically record and aggregate unmet maintenance needs at the tactical level. Even if units do find some ways to increase spare part spending, the moving average methodology without an additive trend component will not result in a higher forecast than that dictated by the most recent year of demand history. Indeed, the only ways for budgets to increase are an increase in OPTEMPO, an influx of additional cash during a year to meet apparent funding and maintenance shortfalls, a policy change, or an increase in part prices either from component repair costs or from supplier prices. Thus, hard budget constraints, the lack of a trend component in the Operation and Maintenance, Army (OMA) budget process, and the absence of unmet maintenance needs tracking likely combine to dampen the effect of any age-cost relationship.

Unit Behaviors May Hide the Effects of Aging from the OMA Budget

Because a unit cannot spend beyond its budget, it may adopt certain coping behaviors to extend its purchasing power in an attempt to meet equipment readiness goals. However, these behaviors might obscure the effects of aging from the OMA OPTEMPO budget process. For example, a unit might go outside the standard supply system to obtain parts by directly asking a direct support (DS) mechanic to repair or rebuild a component carcass rather than turning in the carcass for credit and requisitioning a new part from the military supply system. This would be advantageous from a financial standpoint when the parts needed to complete the repair are less than the average repair cost at the national level (as military labor is not charged to units). Also, units might attempt to increase their cash flow by turning in serviceable—but currently unneeded—parts for credit. Such transactions will not be reflected in the OMA OPTEMPO budget process.

The Impact of Unit Turn-in Behavior Can Be Assessed

These dampening and obfuscating factors and data limitations hamper a thorough analysis of an age-cost relationship. However, we were able to assess the impact on costs of spare part turn-in practices using Corps/Theater Automated Data Processing Service Center (CTASC) document history files. We did this by analyzing the difference between two measures of a unit's spare part costs,

the "exchange price estimate" and "actual expenditures," and whether they have different relationships to tank age.

The exchange price valuation ignores variations in turn-in behavior and is an estimate of the economic value of a unit's part requests. The exchange price estimate assumes that whenever a unit submits a request for a reparable part, it turns in an unserviceable carcass for credit; the estimate also ignores serviceable turn-ins. In contrast, the actual expenditures estimate simply represents total estimated outlays minus total credits based upon actual issues and turn-ins.

Unit Turn-In Behavior Affects Spare Parts Spending

If a unit's actual expenditures are significantly lower than its exchange price estimate, this indicates that the unit may have used turn-ins to stretch its budget. Our analysis found that the relationship between actual expenditures and the exchange price valuation of spare part costs varies substantially. Figure S.1 compares exchange price estimates and actual expenditures for units in six locations. The exchange price estimate is shown on the horizontal axis, while actual

Figure S.1
Unit Turn-in Behavior Affects Spare Part Spending
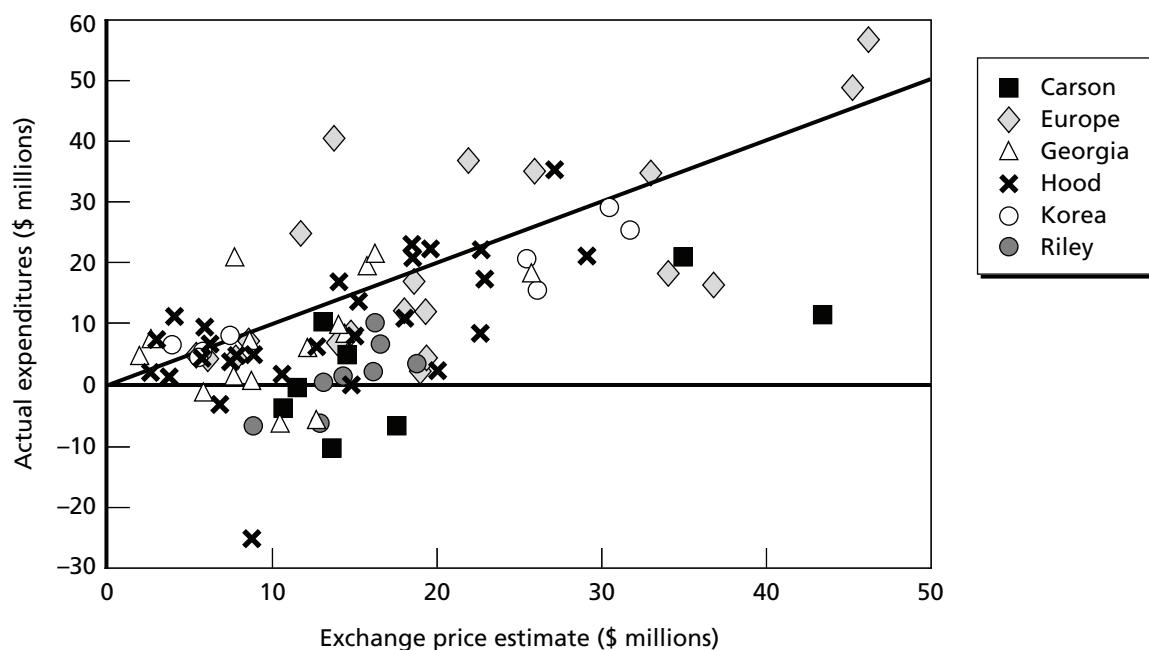
expenditures are on the vertical axis. Points lying "below" the diagonal line indicate brigade-year observations whose actual expenditures are lower than their exchange price estimates. These results suggest that some units, particularly those at Forts Riley and Carson, may have used turn-ins to stretch budgets.

The Analysis Found No Statistically Significant Age-Cost Relationship

Our analyses of the available data found no statistical evidence of an age effect on M1 spare part costs, for either M1A1s or M1A2s, whether examining actual expenditures or exchange price estimates. Thus, by themselves, turn-in practices are not sufficient to obscure an age-cost relationship. Figure S.2 shows the relationship between spare part costs per kilometer and average age of M1A1s for units at six locations. Each point in the graph represents the average age of M1A1 tanks in a brigade and the exchange price estimate of spare part costs adjusted for total usage for the brigade over one fiscal year between 1999 and

Figure S.2
Average Age Does Not Positively Affect M1A1 Exchange Price Estimate
When Adjusted for Total Usage
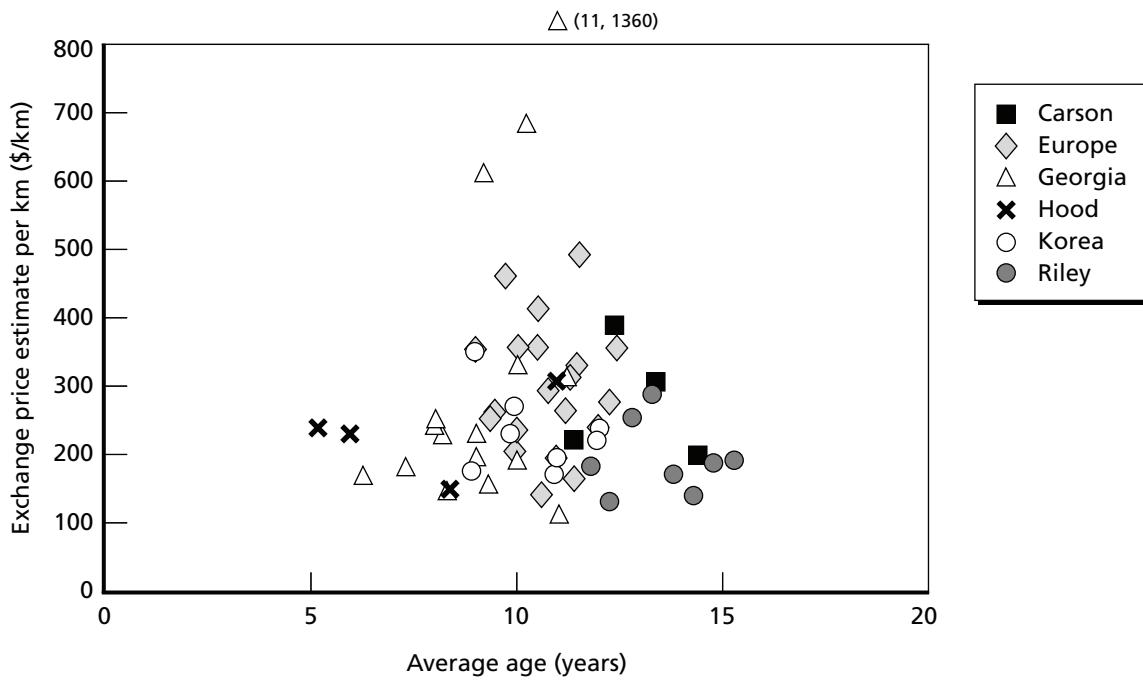
2002. There is no upward trend in the figure, visually confirming that units with older tanks do not necessarily have higher spare part costs (based upon exchange prices), even when adjusted for total usage. We found similar results for M1A2s, and for actual expenditures of spare part costs.

However, because of the mitigating factors discussed above, these results should not be interpreted to mean that equipment age has no effect on maintenance costs. This study should only be taken as an indication that if there is a relationship between tank age and spare part costs, it is suppressed by other factors or a lack of individual tank-level data on maintenance costs.

More Refined Data May Permit Improved OMA OPTEMPO Budget Process

More refined data are needed to conduct a conclusive study on the effects of equipment age on maintenance costs. Labor costs are not fully tracked, and some transactions, such as local purchases and workarounds, are missing from databases. Increased visibility of missing transactions and the ability to link part orders and labor costs to individual end items would allow the application of economic useful life models to better estimate future maintenance costs. Without quantitative results linking age to costs, budget increases will remain difficult to justify.

A full accounting of maintenance costs may also permit an improved OPTEMPO budgeting process. Currently, the OPTEMPO budget process assumes that a unit's requisition history accurately reflects its spare part needs. More refined data would allow the OPTEMPO budget process to take into account costs that may otherwise remain hidden. Other potential improvements to the budget process would be to include a trend component and to reduce the lag time between the calculation of the cost estimates and the final budget proposal.

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We are grateful to Sharon Gilbert, Karen Weston, and Donita Wright at the Army Materiel Command Logistics Support Agency for providing database extracts of tank year-of-manufacture and usage. Abimael Castro, Team Abrams Operations Officer at Fort Hood, provided helpful information on Project Manager Abrams support for M1A2s.

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Glossary

ACR	Armored Cavalry Regiment
AD	Armored Division
ADCDRAC	Advice Code or Return Advice Code
AFTOC	Air Force Total Ownership Costs
ALWCRPCT	Allowable Credit Percent
AMC	Army Materiel Command
AMDF	Army Master Data File
AMSAA	Army Materiel Systems Analysis Activity
AR	Armor Regiment
ARI	Automatic Return Item
ASL	Authorized Stockage List
AVN	Aviation Brigade
AWCF	Army Working Capital Fund
BCT	Brigade Combat Team
CAV	Cavalry Division
CBO	Congressional Budget Office
CSA	Chief of Staff, Army
CTASC	Corps/Theater Automated Data Processing Service Center
DLA	Defense Logistics Agency

DLR	Depot-Level Reparable
DoD	Department of Defense
DODAAC	Department of Defense Activity Address Code
DOL	Directorate of Logistics
DON	Document Order Number
DS	Direct Support
DS/RX	Direct Support/Reparable Exchange
EDA	Equipment Downtime Analyzer
FCS	Future Combat Systems
FedLog	Federal Logistics Catalog
FLR	Field-Level Reparable
FORSCOM	U.S. Army Forces Command
FY	Fiscal Year
GS	General Support
HFYDP	Historical Future Years Defense Program
ID	Infantry Division
ILAP	Integrated Logistics Analysis Program
IMA	Installation Management Agency
LAC	Latest Acquisition Cost
LOGSA	Logistics Support Agency
MACOM	Major Command
MATCAT	Materiel Category
MR	Maintenance Repair
MSB	Main Support Battalion
NET	New Equipment Training

NIIN	National Item Identification Number
NTC	National Training Center
O&M	Operation and Maintenance
OMA	Operation and Maintenance, Army
OMAR	Operation and Maintenance, Army Reserve
OMNG	Operation and Maintenance, National Guard
OPTEMPO	Operating Tempo
OSMIS	Operating and Support Management Information System
PLL	Prescribed Load List
PM	Project Manager
POL	Petroleum, Oils, and Lubricants
RECAP	Recapitalization
RIC	Routing Identifier Code
RON	Request Order Number
SAFM-CE	Assistant Secretary of the Army, Financial Management and Comptroller (Cost & Economics)
SAMS	Standard Army Maintenance System
SARSS	Standard Army Retail Supply System
SMA	Supply Management Army
SSA	Supply Support Activity
SSF	Single Stock Fund
TAMMS	The Army Maintenance Management System
TEDB	TAMMS Equipment Database
TIM	Transformation of Installation Management
TOE	Table of Organization and Equipment

ULLS-G   Unit Level Logistics System-Ground

USACEAC   U.S. Army Cost and Economic Analysis Center

VAMOSC   Visibility and Management of Operating and Support Costs

YOM   Year-of-manufacture

Introduction

M1 Abrams Tank Fleet Is Aging

As the Army transitions from its current force to the Future Force, it must continue to maintain the mission capability of its current weapon systems, such as the M1 Abrams tank, with an affordable budget. GEN Schoomaker, Chief of Staff, Army (CSA), estimates that the M1 tank fleet "is still going to be in this Army out to 2030,"[4] with the Future Combat Systems (FCS) beginning to replace the M1 fleet by the middle of the next decade.

Army personnel have argued that aging equipment is resulting in increased maintenance costs and is leading to decreased readiness as failure rates climb. Thus, recapitalization (RECAP) programs have been targeted at older equipment items, to renew and upgrade their capabilities and extend their service lives.

RAND Study Showed Link Between Tank Age and Mission Critical Failures

Readiness is a function of the mission critical failure rate and maintenance turnaround or "broke-to-fix" time. As part of research on the effects of age on readiness, a recent RAND Arroyo Center study found a relationship between M1 tank age and mission critical failures.[5] Holding maintenance turnaround

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[4] "Army Times Interview with Army Chief of Staff Schoomaker," *Army Times*, April 13, 2004. http://www.armytimes.com/print.php?f=1-292925-2808472.php (accessed June 9, 2004).

[5] Eric Peltz et al., *The Effects of Equipment Age on Mission Critical Failure Rates: A Study of M1 Tanks*, Santa Monica, CA: RAND Corporation, MR-1789-A, 2004, p. 27.

There is no evidence that units with older tanks possess increased resources that would lead to decreased turnaround time; all units of a given type receive the same manpower authorization, and brigade-level spare

time constant, the study predicted that increased equipment age would result in decreased readiness. The research estimated a 5 percent growth rate in M1 tank mission critical failures with age, i.e., a doubling of failures over the first 14 years of tank age. Interestingly, the study found that high-cost parts produce little of this age effect; that is, high-cost parts fail at similar rates for young and old tanks.[6] Instead, the types of failures that were found to increase with age involved less expensive, wear-and-tear type parts. Because high-cost parts dominate M1 spare part spending,[7] these findings suggest that studies analyzing M1 tank age and spare part costs may not find a strong relationship.

Studies Have Not Shown a Quantitative Age-Cost Link

Indeed, empirical studies linking increased equipment age to increased maintenance costs have not been conclusive, making budget justifications difficult. A recent Congressional Budget Office (CBO) study did not find a link between M1 tank age and operating costs.[8] Additionally, the CBO study found no evidence of a relationship between fleet age and Department of Defense (DoD) mission-related Operation and Maintenance (O&M) spending, although it did find that age affected aircraft maintenance costs.[9] The report suggested that fu-

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part inventory criteria are set independent of equipment age. If older tanks fail more often, then the higher rate of spare part demand would result in greater inventory recommendations. But these greater levels would be necessary simply to maintain inventory and part wait time performance. The inventory will generally not increase to a greater degree than the failure rate, which would be necessary to reduce part wait and thus repair turnaround time.

[6] Ibid., p. 48. The cost of a spare part is considered "high" if its unit price exceeds $10,000.

[7] Our analysis of fiscal years (FYs) 1999–2002 revealed that spending on high-cost parts in active brigade-sized units with M1 tanks averaged about 70 percent of all spare part expenditures. This percentage did not include turn-ins.

[8] Congressional Budget Office, *The Effects of Aging on the Costs of Operating and Maintaining Military Equipment*, August 2001, p. 17.

The estimate of operating costs was obtained from the Operating and Support Management Information System (OSMIS) database. Note that during the 1993–1999 period of the CBO study, OSMIS only tracked purchases from the wholesale supply system. It did not include referrals, local Authorized Stockage List (ASL) issues, turn-ins, or items repaired in local General Support (GS) or Direct Support/Reparable Exchange (DS/RX) programs.

[9] Ibid., p. 7 (mission-related O&M spending) and p. 33 (aircraft O&M spending).

The estimate of mission-related O&M spending was obtained from the Historical Future Years Defense Program (HFYDP). In the HFYDP, mission-related O&M spending covers the cost to train and operate combat forces that may be deployed, which includes the cost of repairing and maintaining equipment.

ture studies at the serial number level—enabled through better tracking of failures, labor, and parts—might be more effective at revealing any relationship between age and operating costs.[10] However, data limitations continue to hamper cost studies based upon serial number level data.

Despite these limitations, this research uses requisition and turn-in data and tank mileage and age data to study the effects of equipment age on spare part costs at the brigade level. It discusses the data limitations and mitigating factors that hinder conclusive studies on age and M1 maintenance costs, analyzes the available data, and pinpoints gaps in the Army's data capture and business processes that need to be filled in order to conduct thorough analyses on the effects of age on costs. This research, which addresses the effects of equipment age on financial costs, is a companion piece to Peltz et al. (2004), which studied the effects of age on readiness.

Organization of this Document

The remainder of this document is organized as follows. Chapter Two provides a summary of the different mitigating factors that either dampen any age-cost relationship or hamper a comprehensive analysis of the effects of equipment age on maintenance costs, including a discussion of the spare part budget process. Chapter Three focuses on the potential effect of one mitigating factor—turn-in of serviceable parts to alleviate budgetary constraints—on spare part spending. Chapter Four uses the available data to perform an analysis of the effects of age on spare part costs, with and without turn-in behavior. Chapter Five offers some recommendations to improve maintenance cost accounting and budgeting processes.

The appendixes provide supporting technical information. Appendix A summarizes the data characteristics. Appendix B describes the method by which

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Estimates of aircraft O&M costs were obtained from three different sources: (1) Air Force Total Ownership Costs (AFTOC), (2) the Navy's Visibility and Management of Operating and Support Costs (VAMOSC), and (3) the HFYDP.

Note the slight but important differences in definitions of O&M spending between that found in the OSMIS database and that in the HFYDP. HFYDP O&M spending on deployable units includes O&M spending on military equipment and other nonequipment expenses. See pp. 8–10 of the CBO document for more information.

[10] Ibid., p. 22.

turn-in credit was determined prior to the implementation of Single Stock Fund (SSF). Appendix C contains request and turn-in data for two brigade-year observations with negative actual expenditures. Appendix D provides additional statistical information about the age and spare part cost analyses.

Mitigating Factors in Studies of the Effects of Equipment Age on Maintenance Costs

This chapter discusses the factors that can hamper studies of the effects of equipment age on maintenance costs. We begin with a discussion of the spare part budget process, including how it may dampen age-cost effects. Then we describe some unit behaviors that may be used to alleviate budgetary restrictions and may work to obscure the effects of aging. Finally, other mitigating factors and data limitations are discussed.

Maintenance Costs Within the Army Budget

To begin our discussion of maintenance costs, we first review the Army's budget structure. The Army budget is divided into accounts, three of which contain maintenance costs: Operation and Maintenance (O&M), Military Personnel, and Procurement. O&M covers the cost of operating equipment, institutional training, mobilization operations, training missions, and installation management;[11] Military Personnel covers military pay, incentives, subsistence, and change of station costs; and Procurement covers the costs associated with the acquisition of new equipment, including initial spare parts and some modifications. Equipment maintenance costs are estimated to account for about 12 percent of the total Army budget.[12]

Each account is further subdivided into three components to cover expenses for the Active, Reserve, and National Guard components of the Army. For the O&M account, these budgets are called OMA, OMAR, and OMNG,

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[11] O&M also includes spending on civilian and contract personnel, health care, environmental programs, real property maintenance, base operating support, and communications.

[12] Eric Peltz, *Equipment Sustainment Requirements for the Transforming Army*, Santa Monica, CA: RAND Corporation, MR-1577-A, 2003, p. 12 and Appendix C.

respectively. In this study, we focus on the Active component. In particular, we focus on expenditures for spare parts required by operating units and supporting installation maintenance activities to perform repairs and conduct scheduled maintenance (as opposed to depot-level overhauls, which are also part of the O&M budget, and as opposed to expenditures for labor, petroleum, oils, and lubricants [POL], etc.). Within the OMA budget, spare part funding is provided through the operating tempo (OPTEMPO) budget. Funds from the OPTEMPO budget may also pay for civilian and contract labor for maintenance.

OMA OPTEMPO Budget Process

For each major weapon system variant, the OMA OPTEMPO spare part budget process takes a moving average of three years of spare part demand history, using updated prices and credits, to determine a cost-per-mile factor.[13] Funds are allocated by major command (MACOM) and are determined by multiplying the cost-per-mile factor by the number of end items and planned OPTEMPO for each.[14] Each MACOM then distributes the funds to its subordinate units, which cannot spend beyond their budgets.[15]

Determination of Turn-in Credit

Budgets are set with the expectation that for each demand for a reparable item, operating units will receive credit for returning a carcass, i.e., a part that can be repaired.[16] Until recently, the amount of turn-in credit awarded depended on whether an item was a depot-level reparable (DLR), field-level reparable (FLR),

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[13] The spare part demand history used for developing the OPTEMPO budget is captured in OSMIS.

Note that because of data availability issues and the length of time required to create a budget that must be approved by both the President and Congress, the three years of demand history used typically represent data that are 3–5 years old by the time the budget is passed.

[14] The planned OPTEMPO has typically been 800 miles for tanks in the Active component of the Army. See Appendix A for information on reported OPTEMPO over time.

Part expenditures or purchases could be different for different MACOMs even when average part costs per mile are the same, because each MACOM independently determines the parts that it will repair locally.

[15] Some adjustments may be made to the initial funding level prior to distribution of OPTEMPO funds to the MACOMs. MACOMs typically hold some funds in reserve prior to the distribution of funds to their subordinate units.

[16] Note that this expectation is not borne out by the data. See Appendix C of this document, and p. 48 of Ellen Pint et al., *Right Price, Fair Credit: Criteria to Improve Financial Incentives for Army Logistics Decisions*, Santa Monica, CA: RAND Corporation, MR-1150-A, 2002.

or consumable item; whether it was serviceable or unserviceable; and whether it was needed at the *local* level or not. (See Appendix B for more details.) However, the credit received for these parts changed with the advent of Single Stock Fund (SSF), which began implementation in fiscal year (FY) 2001. SSF was instituted to streamline the financial management system and improve inventory management by merging the Army's retail and wholesale stock funds.[17] Under SSF, turn-in credit depends on whether the item is reparable or not; serviceable or unserviceable; and whether the item is needed at the *national* level or not.

Lack of Trend Component Dampens Spending

Note that the OMA OPTEMPO budget process has no trend component to account for projected increases in spare part needs. In particular, since budgets are not explicitly adjusted for equipment age, units will not necessarily have funds available to pay for spare part consumption increases due to age. Because units cannot spend beyond their budgets, a unit's aggregate spare part spending across all supported end items typically cannot "float" to meet increased spare part needs. Moreover, the Army does not record unmet maintenance needs at the tactical level, so there is no mechanism for "adjusting" a unit's demand history upward. Thus, the moving average methodology and lack of a trend component results in a forecast that will be no greater than the level dictated by the most recent year of demand history. Hence, there are only a few ways for budgets to increase: an increase in OPTEMPO; an "intervention," i.e., an influx of additional cash during a year to meet apparent funding and maintenance shortfalls; a policy change; or an increase in part prices either from component repair costs or supplier prices.[18] Therefore, the lack of a trend component in the OMA budget process, the absence of unmet maintenance needs tracking, and hard

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[17] More information on SSF can be found at http://www.army.mil/ssf (accessed September 15, 2002).

[18] Many components are rebuilt at the depot level. If the level of rebuild goes up, the cost of restoring these components could increase. These costs are passed on to units through lower credits for turn-ins, and budgets are adjusted to reflect credit changes.

Army personnel at SAFM-CE (Assistant Secretary of the Army, Financial Management and Comptroller [Cost & Economics]) have stated that exchange prices have increased by about 10 percent per year in recent years due to repair cost growth and decisions to cut off credits for some items considered to be in long supply. We investigated this claim using both unweighted and weighted (by number of demands in a fiscal year) average exchange prices, and we did not see an increase in either average exchange price in FYs 1999–2002 for Abrams parts. We did not examine exchange price trends for other weapon systems.

budget constraints all probably contribute to a dampening effect on the age-cost relationship.

Various Unit Behaviors May Hide the Effects of Aging

As a direct result of the fact that units may not spend beyond their budgets but are still under pressure to maintain readiness, various unit behaviors have been observed that may obscure the effects of aging. As discussed in the next chapter, units may turn in for credit serviceable parts or unserviceable parts without a matching purchase. In addition, units may adapt their spare part ordering behavior or selectively reduce part orders. These behaviors may have readiness implications as well.

Units May Adapt Part Requests and Shift Resources

A unit may go outside the standard supply system to obtain parts, and thus its demand history may not accurately reflect its part needs. For example, some parts may be obtained through local purchase or maintenance-to-maintenance transactions. While some local purchase records are kept, transaction details are not generally recorded in the demand history. In a maintenance-to-maintenance transaction, a mechanic may ask a co-located direct support (DS) mechanic to repair or rebuild a carcass as opposed to turning the carcass in for credit and requisitioning a new part from the military supply system.[19] Military labor is "free" from the perspective of the unit,[20] so the resources used to repair an item will not be fully accounted for in a unit's spare part demand history. Thus, while a unit's spare part costs may have been minimized, overall costs to the Army may not be in the long run, because of the opportunity cost involved when DS mechanics repair items typically repaired at other facilities or because of the additional apparent demand on DS mechanics that drives their authorized level.

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[19] Note that the planned elimination of some DS engine repair capabilities at units will decrease their ability to repair high-priced parts as opposed to requisitioning them. Note also that the reliability of serviceable parts produced by different providers is not tracked, so potential issues such as higher failure rates are hidden by a lack of metrics.

[20] The Military Personnel budget is managed centrally, unlike the O&M budget, which allocates OPTEMPO funds to its subordinate units. Units are not charged for their military personnel.

Units may also shift resources by engaging in controlled exchange or "cannibalization." This involves additional maintenance workload. However, since the Army does not pay overtime, no additional costs are apparent.

Another example of resource shifting involves MACOM spare part redistribution centers. In order to avoid turning in serviceable items to the Army Working Capital Fund (AWCF) for little or no credit, only to later requisition them at full price, MACOMs set up redistribution centers. Turn-ins could then be kept within OMA budget accounts and redistributed to other units within the MACOM. The redistribution centers were also used to repair items for distribution to units within the MACOM. These requirements were not counted in the OPTEMPO budget process at the national level. After the implementation of SSF and the elimination of the retail stock fund, this was no longer possible at the MACOM level.[21]

Units May Selectively Reduce Part Requests

A unit may also selectively reduce part orders, say, by performing only dead-lining maintenance. Or, a unit may strategically delay replenishment of its Prescribed Load List (PLL) inventory or shop stock until budget pressures have lifted. Both of these behaviors have readiness implications.

Prior to FY 2001, additional financial incentives existed to minimize spare part consumption. During that time, OPTEMPO funds were fungible and could be used for other priorities, such as base operations, training, and real property maintenance.[22] For example, leftover money could be used for quality-of-life enhancements to a post. Beginning in FY 2001, GEN Shinseki (then Chief of Staff of the Army) issued guidance to stop the migration of

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[21] However, the basic process migrated to the national level, where it is now used by Army Materiel Command (AMC) to avoid the loss of AWCF dollars to the Defense Logistics Agency (DLA). An example is the Sierra Army Depot, identified by Routing Identifier Code (RIC) AJ1; this center was established to hold and redistribute assets returned from southwest Asia.

[22] Donald Friend, Wyllo Hanson, and MAJ Todd Calderwood, "Protecting Army Readiness Training Funds," *Resource Management*, 3rd/4th Quarter 2001, p. 23. Available at http://www.asafm.army.mil/proponency/rm-mag/fy2001/1201rm.pdf, accessed August 10, 2005.

Note that OPTEMPO dollars for parts for various systems become pooled when they are distributed, so it is possible for the manner in which the money is spent to change; the total amount across systems and OPTEMPO items has less flexibility unless additional dollars are provided from other sources.

OPTEMPO dollars to other accounts.[23] This guidance was later formalized under Transformation of Installation Management (TIM).[24] Under TIM, base operating support budgets are fenced and under the control of the Installation Management Agency (IMA). Thus, the incentive to reduce spare part expenditures in order to use "surplus" dollars for other purposes has diminished.

Other Mitigating Factors and Data Limitations

In addition to the OPTEMPO budget process and unit behaviors, other mitigating factors and data limitations hamper studies of the effects of age on maintenance costs. First, studies have typically focused on O&M costs, ignoring military labor costs, which are paid for out of the Military Personnel account. Peltz et al. (2004) concluded that mission critical failures increase with age, suggesting that labor hours are likely to show an age effect. However, data limitations preclude an accurate accounting of maintenance labor hours. Organizational maintenance hours are not measured, and the quality of the data for direct and general support labor is suspect.[25] Without an accurate accounting of labor hours and thus costs, it will be impossible to determine whether work requirements are increasing or whether units are using labor to work around part delivery delays. The lack of labor data, especially those linked to particular end items, also makes it difficult to apply commercial "economic useful life" models that help determine when to replace an aging end item.

Moreover, military manpower authorizations do not vary with age across a fleet. A unit's Table of Organization and Equipment (TOE) is independent of equipment age; e.g., units with older M1A1 tanks are assigned the same number of mechanics as those with newer M1A1 tanks. In addition, military personnel do not receive overtime pay, so in the short run, military labor is a fixed cost regardless of the number of hours actually worked. On the other hand, the costs of government civilian personnel or contractors could vary with

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[23] As cited in U.S. House of Representatives, *Report to Congress, Subject: OPTEMPO Training Resource Metrics*, Washington, D.C., U.S. Government Printing Office, July 2002.

[24] TIM was implemented in FY 2003. More information on TIM can be found at http://www.hqda.army.mil/ acsimweb/IMAImplementationPlan.shtml (accessed August 1, 2003).

[25] While the Standard Army Maintenance System (SAMS) does track direct and general support maintenance hours, confidence in the recorded man-hours is not high. Unit Level Logistics System-Ground (ULLS-G) tracks organizational-level maintenance but does not record maintenance man-hours.

equipment age, but these costs are also not well documented. Thus, the full costs of labor are hidden from budgets.

Finally, a lack of end item maintenance histories contributes to the difficulty in determining a tank's "true" age. As part of its maintenance, a tank typically undergoes significant component renewal. At present, however, a lack of historical maintenance records hampers the ability to use a more refined definition of equipment age than the age of its hull. Similarly, overhaul data are limited.

All of these mitigating factors and data limitations hinder efforts to study the effects of equipment age on maintenance costs. The impact of one mitigating factor may still be estimated using the available data: the use of unit turn-ins. This topic is the subject of the next chapter.

Analysis of Unit Turn-In Behavior

This chapter uses the available data to estimate the extent of unit turn-in behavior: the turn in of serviceable parts and unserviceable parts without a matching purchase to alleviate budget constraints. To do so, we define two different estimates of spare part costs: actual expenditures and an exchange price-based valuation of spare part demands. By comparing these two estimates, we assess the extent that turn-in behavior affects expenditures.

Valuation of Spare Part Demands

Actual Expenditures

Actual expenditures are total outlays minus total credits.[26] This value represents the actual "cash" or OPTEMPO budget used. The actual expenditures calculation includes serviceable and unmatched unserviceable turn-ins.[27] Each request is valued at its Army Master Data File (AMDF) price, and each turn-in is valued at the amount of credit received.

AMDF prices and credits were obtained from the January Federal Logistics Catalog (FedLog) for each fiscal year to best reflect actual expenditures. For example, a request initiated in June 2001 reflects the AMDF prices in the January 2001 FedLog. U.S. Army Cost and Economic Analysis Center (USACEAC) factors were used to adjust prices to FY 2002 dollars, controlling for inflation.

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[26] Note that actual expenditures may be negative if total credits exceed total outlays.

[27] An unmatched unserviceable turn-in is a turn-in of an unserviceable item without an associated request for a serviceable replacement.

Then year prices (adjusted to FY 2002 dollars) were used to approximate, as closely as possible, actual costs incurred and credits received.[28]

Recall that in FY 2001, the method for determining turn-in credit changed. Pre-SSF credit policy was used for FYs 1999–2000; Appendix B details the method by which turn-in credit was determined prior to the implementation of SSF. SSF credit policy was used for FYs 2001–2002; the SSF credit determination process was introduced in Chapter Two.

Exchange Price-Based Valuation

This valuation is an estimate of the economic value of parts demanded by units. The exchange price-based estimate ignores variations in turn-in behavior, and it values requests for consumables at their AMDF price and those for reparables at the Supply Management Army (SMA) surcharge allocation plus average repair cost (or, AMDF price minus unserviceable credit).[29] In other words, the exchange price estimate assumes no serviceable turn-ins and a one-to-one ratio of reparable requests to unserviceable carcass turn-ins. Note that the OMA OPTEMPO budget process is also based on these assumptions.

For the exchange price estimate, the AMDF prices and credits associated with each prime National Item Identification Number (NIIN) were obtained

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[28] The Army uses "prime" National Item Identification Numbers (NIINs) to identify items in supply through its logistics systems. Some items, called "related" NIINs, may be designated as interchangeable or substitutable for the "prime" NIINs. These related NIINs were not replaced by their prime NIIN for this calculation, because credit for an obsolete NIIN should not be determined by an interchangeable or substitutable NIIN.

We chose the FedLog from January of each fiscal year to allow for price fluctuations from year to year, but not within a single fiscal year. In 1992, the services were required to procure and repair all DLRs using the working capital fund. Because Supply Management Army (SMA) financial managers are responsible for maintaining the solvency of the fund, AMDF prices and credits are set in such a way that the stock fund should break even over a two-year budget period. Prior to SSF, AMDF prices and serviceable and unserviceable credits could vary from month to month within a fiscal year. We chose the FedLog from January because prices and credits had typically settled down by that time. After SSF, prices and credits were set for the entire fiscal year. For more details, see Chapter One of Marygail Brauner et al., *Dollars and Sense: Applying a Process Improvement Approach to Logistics Financial Management*, Santa Monica, CA: RAND Corporation, MR-1131-A, 2000.

[29] The AMDF price is equal to the latest acquisition cost (LAC), plus the SMA surcharge that covers supply management costs of operation, including overhead, warehousing, and transportation, and offsets for prior-year losses or gains. Overhead includes the costs of cataloging, accounting, and personnel.

The AMDF unserviceable credit is equal to the LAC minus the average cost to repair, adjusted for washouts.

Note that the exchange price estimate cannot be a negative value.

from the January 2002 FedLog to hold part value, namely SMA surcharge and average repair cost, constant in FY 2002 dollars over time.[30]

Table 3.1 illustrates the difference between the two calculations. Assume that a unit requests one $5 reparable item (with a $2 unserviceable credit) but does not turn in a matching carcass. At the same time, the unit turns in one serviceable reparable with a $4 credit. The actual expenditures calculation is $5 – $4 = $1, reflecting the purchasing power actually used by the unit. By contrast, the exchange price estimate—the estimated economic value of the request—is $5 – $2 = $3, because it ignores the unmatched serviceable turn-in and assumes the reparable request is accompanied by an associated carcass turn-in.[31]

By defining actual expenditures and the exchange price estimate in this manner and by comparing the two values, it is possible to assess the effect of unit turn-in behavior on spare part costs.

Data Sources and Methodology

Requisition and turn-in data for the analyses were obtained from the Corps/Theater Automated Data Processing Service Center (CTASC) document

Table 3.1
Examples of Actual Expenditures and Exchange Price Estimate

Two Calculations	Actual Expenditures	Exchange Price Estimate
Example: Request one $5 reparable ($2 unserviceable credit) without an associated carcass turn-in	$\sum$ requests at AMDF price – $\sum$ turn-ins at credit value (includes all turn-ins: serviceable and unserviceable)	$\sum$ requests at (AMDF price – unserviceable credit) (assumes one-to-one request to carcass turn-in ratio and no serviceable turn-ins)
Turn in one serviceable reparable with $4 credit	Actual Expenditures = $5 – $4 = $1	Exchange Price = $(5 – 2) = $3

[30] The Army uses "prime" NIINs to identify items in supply through its logistics systems. Some items, called "related" NIINs, may be designated as interchangeable or substitutable for the "prime" NIINs. These related NIINs were replaced by their prime NIIN in our exchange price calculations.

[31] An example of how this could be advantageous to an organization: if the carcass in the example had been repaired for less than $2, then the unit would have saved money by repairing the carcass and turning it in for serviceable credit. This is possible because the unserviceable credit is based upon average cost to repair, and the unit could elect to do a less thorough repair or the repair may be "easier" than the average repair.

history files.[32] CTASC data are used, as opposed to OSMIS data, because prior to FY 2001, OSMIS only measured purchases from the wholesale supply system.[33] Only transactions for M1 Abrams spare parts from active units with M1 tanks are included.[34]

Each transaction was assigned to a brigade based upon the support Routing Identifier Code (RIC) used in the request.[35] The support RIC identifies the supply support activity (SSA) that directly supports the maintenance activity.[36] Organizational maintenance requests can be traced to an individual tank company or cavalry troop and hence to its commanding brigade or cavalry regiment. DS maintenance requests can only be traced to a brigade, though, which can include one or two tank battalions. Requisitions for tank parts originating at main support battalions (MSBs) are allocated proportionally across all brigades in the division. Part requests from General Support (GS) or Directorate of Logistics (DOL) maintenance are also assumed to be for the benefit of all tanks potentially supported by the activity and allocated proportionally across all supported brigades.[37]

Estimates were calculated for 22 active brigades with M1 tanks between FYs 1999 and 2002. There are 60 M1A1 brigade-year observations and 20

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[32] CTASC document history files are compiled from data supplied by the Standard Army Retail Supply System (SARSS) computer. These data were obtained from the Logistics Support Agency (LOGSA) for FYs 1999–2002.

[33] In particular, it did not include referrals, local ASL issues, turn-ins, or items repaired in local GS or DS/RX programs.

[34] By combining OSMIS cost drivers with a list of M1 deadlining parts obtained from the O26 prints in SAMS, we designated 6221 NIINs as "M1 Abrams spare parts."

 Active brigade-sized units included in the study belong to: 3rd Armored Cavalry Regiment (3ACR); 1st Armored Division (1AD); 1st Infantry Division (1ID); 2ID; 3ID; 1st Cavalry Division (1CAV); and 4ID.

[35] This field is called "spt_ric" in the CTASC data.

 From now on, the term "brigade" will be used instead of "brigade-sized unit."

[36] When a unit orders an item, a Request Order Number (RON) is assigned to the request. If the item is not available at the SSA, then the request is established as a due-out at the SSA, which creates a Document Order Number (DON) to order the part, consolidating customer orders as appropriate. This process is often called the RON/DON process. Both the original RON and DON are recorded in SARSS and hence in CTASC. In our data, requisitions were limited to those originating from customer Department of Defense Activity Address Codes (DODAACs); that is, DONs were excluded.

[37] The proportional allocation was performed as follows: if an MSB/GS/DOL supports two brigades who spend, say, $3 and $5 on spare parts respectively, then the MSB/GS/DOL's spare part costs are allocated to the two supported brigades in a 3:5 ratio. This has the effect of reinforcing existing ratios of spare part costs among brigades served by the MSB, GS, and/or DOL.

M1A2 brigade-year observations.[38] The estimates were calculated for M1A1s and M1A2s separately, because the tank variants and their spare part costs, i.e., unit prices, are significantly different. See Appendix A for a summary of the data characteristics.

Analysis Shows that Turn-ins Affect Spare Part Spending

A comparison between the two estimates of spare part costs shows that unit turn-ins are affecting spare part spending, with wide ranges of actual expenditures for a given level of exchange price value. Figure 3.1 shows the actual expenditures versus exchange price estimates by location. For example, the lowest point on the graph shows that a brigade from Fort Hood had an exchange price estimate of almost $10 million but actual expenditures of about –$25 million. This figure shows that actual expenditures tend to be lower than the exchange price value of spare part demands, that is, the data points tend to lie "below" the diagonal line, but the relationship between the two has significant variability. This suggests that units may have used serviceable and/or unmatched unserviceable turn-ins to alleviate budgetary pressures, or they may have been ordering unnecessary expensive reparables.[39]

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[38] Technically, there are 22 unit-year observations for M1A2s. However, due to initial part support by the Project Manager (PM) Abrams (now, PM Combat Systems), the spare part needs estimates may have been artificially low for two datapoints. The "warranty" provided M1A2 tanks with fair wear and tear support for repair (Class IX) parts through the completion of New Equipment Training (NET) and for AGT 1500 tank engines up to one year after the start of NET; during this "warranty" period, worn parts were replaced free of charge. The two "warranty" points are 1CAV-1BCT, FY 2002 and 4ID-2BCT, FY 2001. See Appendix D for more details.

[39] See Appendix C for request and turn-in data for two brigade-year observations with negative actual expenditures.

A unit ordering unnecessary expensive reparables may have actual expenditures less than its exchange price valuation if the unit purchases then turns in the unneeded serviceable items. In this case, the actual (serviceable) credit received is greater than the (unserviceable) credit assumed to be received under the exchange price valuation, yielding an actual expenditures estimate less than its exchange price valuation.

Note also that because these data are computed at the brigade level, the SSA may also have taken advantage of credit policies to obtain negative actual expenditures prior to SSF Milestone 3. For example, a unit may turn in an unserviceable item to its SSA for unserviceable credit. The SSA may then ask a co-located repair shop to repair the item and turn in the serviceable tank engine for serviceable credit. The labor to repair this item is "free" from the financial perspective of the SSA, so this may appear to save money from the SSA point of view. Similarly, credit rates are based upon average repair costs. Thus, an O&M activity could save money by "cherry picking" the easy component repairs.

Figure 3.1
Unit Turn-in Behavior Affects Spare Part Spending (by Location)
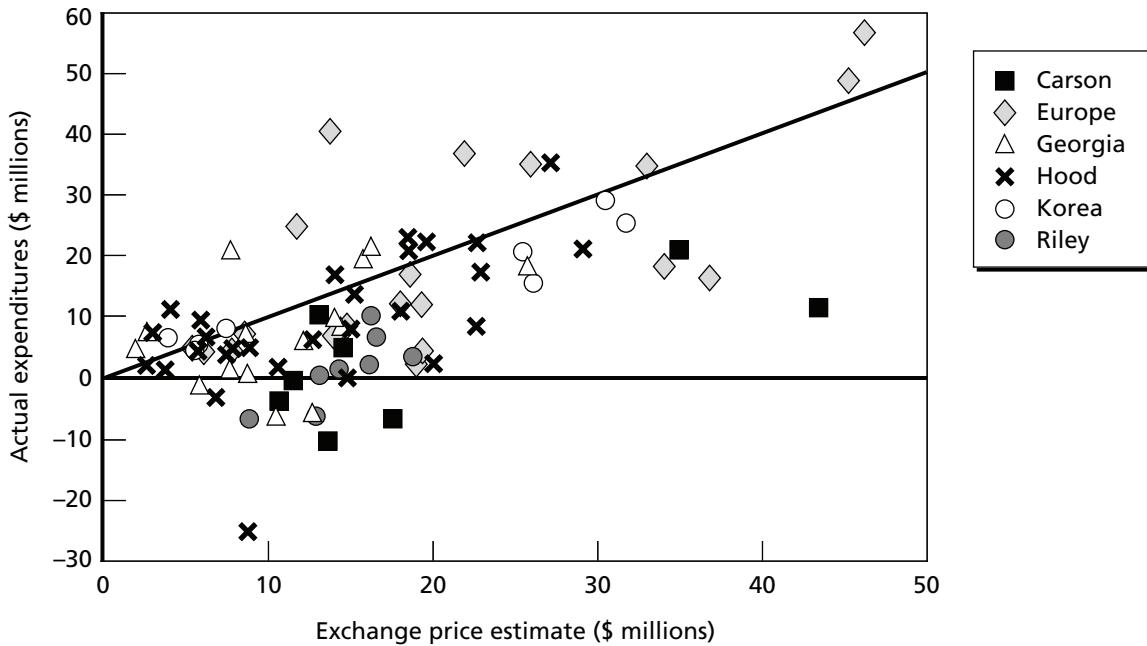
In Figure 3.2, the same data are separated by fiscal year. Recall that SSF Milestone 2—the uniform credit policy—was implemented Army-wide on October 1, 2001. SSF Milestone 3, which capitalized SSA tactical inventory into the AWCF, was completed at most posts by the end of FY 2003.[40] Interestingly, the data for FY 1999 are particularly scattered in comparison to the other

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There may be some windowing effect in these data; that is, because a unit may purchase a reparable in one fiscal year and turn in the unserviceable carcass in a different fiscal year, the data may be somewhat distorted. However, this windowing effect should be minimal, because requests and turn-ins are accumulated over an entire fiscal year.

[40] DS/RX items were not capitalized into the AWCF.
Approximate SSF Milestone 3 implementation dates were as follows:

Carson	November 2002
Europe	December 2002
Georgia	November 2002
Hood	July and November 2002
Korea	May 2003
Riley	November 2002

Figure 3.2
Unit Turn-in Behavior Affects Spare Part Spending (by Fiscal Year)
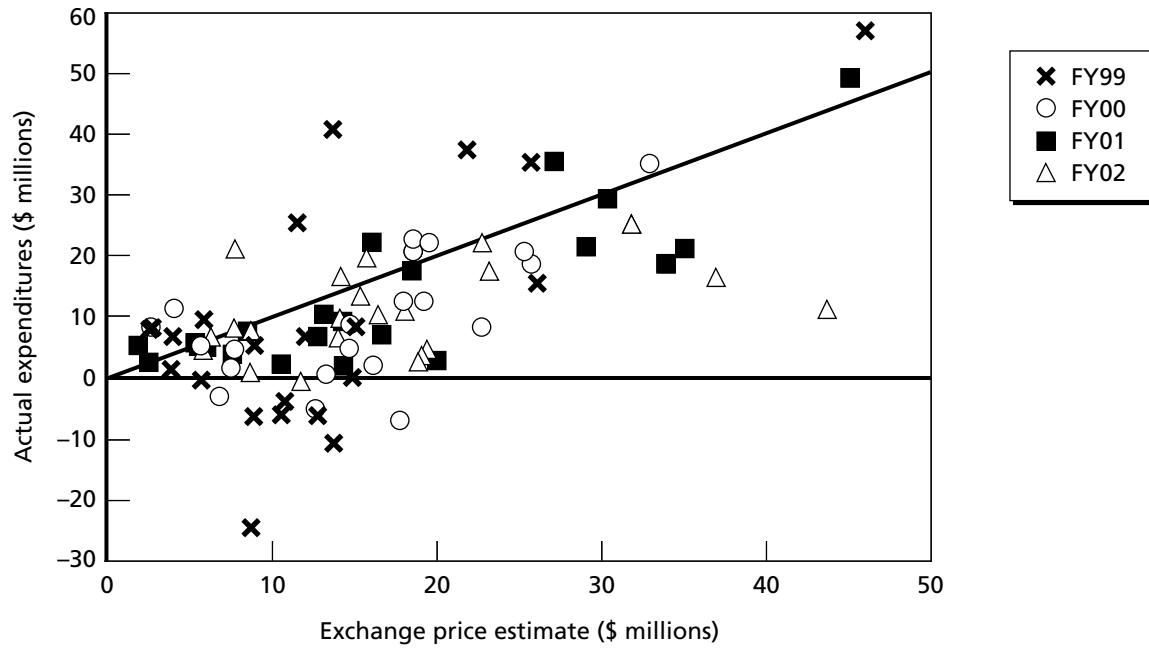
RAND *TR286-3.2*

years. However, most points lie "below" the diagonal line, regardless of fiscal year, reflecting the effects of unit turn-in behavior irrespective of credit policy.

Analysis of the Effects of Equipment Age on Spare Part Costs

In this chapter, despite the many mitigating factors mentioned in Chapter Two that hamper definitive studies on the effect of age on spare part costs, we use the available data to study the effects of equipment age on both estimates of spare part costs, with and without turn-in behavior. We define the study variables, explain our methodology, and conclude with the results of our analyses. However, because actual expenditures reflect potential unit turn-in adaptations, we place more emphasis on the analysis using the exchange price valuation of demands as an estimate of "economic" spare part costs.

Methodology

Average Brigade Tank Age

In this study, the age of a given tank is calculated by subtracting its year-of-manufacture (YOM) from the year of analysis, where YOM data was obtained from The Army Maintenance Management System (TAMMS) Equipment Database (TEDB). For example, a tank manufactured any time in 1997 would be considered two years old for all of FY 1999. The average brigade tank age, or average age, is defined to be the weighted average of tank ages in the unit, weighted according to the fraction of the total time that the tank was assigned to the unit. For example, a unit with a 4-year-old tank assigned to it for half a year and a 6-year-old tank assigned to it for a full year would have an average age of $(4*0.5 + 6*1)/(0.5 + 1) = 5.33$ years.

In Chapter Two we noted that during the life cycle of a tank, many of its components may have been replaced or refurbished. Because overhaul and maintenance records for individual tanks are not available, any observed age ef-

fects in our analyses are those that appear despite component replacement or refurbishment.

Sample Characteristics

Our data sample includes 86 brigade-year observations of average age, actual expenditures, and exchange price estimates of spare part costs. Of these, 60 are for brigade-years with only M1A1s, and 20 are for those with only M1A2s. (The remaining observations are for brigade-years in which both tank variants appear.)

Final Regression Models

Due to the small sample size, simple multivariate linear regression is the most reasonable analytical technique to use.[41] Other predictor variables included in the analysis for control purposes are location,[42] number of tanks,[43] usage per tank,[44] and total brigade tank usage (total usage).[45] The regressions were performed for M1A1s and M1A2s separately, because the tank variants and spare part costs (unit prices) are significantly different.

The final regression models obtained for the exchange price estimate of spare part costs are:

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[41] Typically with repeated measures (of the same brigade, in this case), time series analysis is conducted. But since there are only four repeated measures and each measure uses FY 2000 dollars, it is likely that the effect of the individual predictor variables is more significant than that of time series. Similarly, while graphs of the data suggest that the predictor variables may have different effects by location, the small sample size prevents us from analyzing interaction effects at this time.

[42] "Locations" include Fort Carson, Europe, Georgia (Forts Benning and Stewart), Fort Hood, Korea, and Fort Riley. This variable is included to control for differences specific to location, such as budget allocation practices, training schedule, and terrain.

[43] "Number of tanks" is a weighted average number of tanks, weighted according to the fraction of the total time that the tank was assigned to the brigade. This variable is included to account for differences in brigade size.

[44] "Usage per tank" is obtained from odometer readings from the TEDB. Total brigade usage is the total distance driven by all tanks in the brigade during a given fiscal year. Average usage per tank is the total brigade usage divided by the number of tanks in that brigade as defined in the previous footnote. This variable is included in the regression to account for differences in OPTEMPO.

Due to data limitations, October 15 was considered the beginning of the fiscal year for usage data.

[45] "Total usage" is the total distance driven by all tanks in the brigade during a given fiscal year. It can be equivalently defined as the product of the number of tanks and the average usage per tank. This product is included in the regression analyses, because it is used as part of the OMA OPTEMPO budget process. Other interaction variables were not included because of the small sample size.

$$\text{exchange price estimate}_{\text{M1A1}} = \$1.2M + \$4.4M(\textbf{Europe}) + 208(\textbf{total usage})$$

$$\text{exchange price estimate}_{\text{M1A2}} = \$6.1M + 143(\textbf{total usage})$$

The final regression models obtained for actual expenditures of spare part costs are:

$$\text{actual expenditures}_{\text{M1A1}} = \$25.6M + \$9.3M(\textbf{Europe}) - \$12.4M(\textbf{Hood}) -$$
$$2.8M(\textbf{average age}) + 196(\textbf{total usage})$$

$$\text{actual expenditures}_{\text{M1A2}} = \$7.2M + 75(\textbf{total usage})$$

Our analyses suggest that:

- Increased average age statistically does not lead to increased exchange price estimates or actual expenditures of spare part costs at the brigade level. Increased average age was actually associated with lower M1A1 actual expenditures in this sample.
- Location and total usage are significant predictors of spare part costs.
- Spare part costs in Europe tend to be higher than those at other locations for M1A1s.
- M1A1s appear to accrue costs at a higher rate per mile than M1A2s.
- Some costs appear to be independent of usage.

See Appendix D for more detailed statistical information on the regression analyses.

Regression Analyses Do Not Show a Positive Age Effect on Spare Part Costs

No Evidence of a Positive Age Effect on the Exchange Price Estimate

Our linear regression analyses did not show a statistically significant positive relationship between average age and the exchange price valuation of total spare part demands. Figures 4.1 (M1A1) and 4.2 (M1A2) visually confirm that there is not a strong relationship between the average age of tanks in a brigade and

Figure 4.1
Average Age Does Not Positively Affect M1A1 Exchange Price Estimate
When Adjusted for Total Usage

RAND *TR286-4.1*
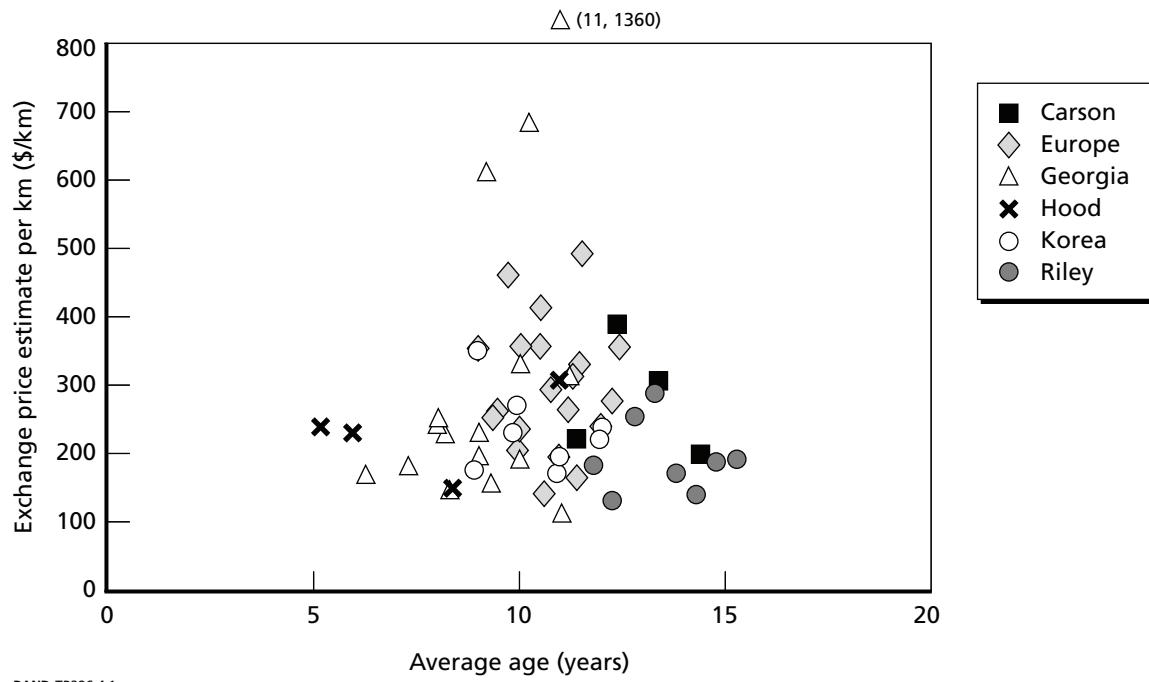
the exchange price estimate when adjusted for total brigade tank usage (total usage); there is no upward trend in any of the graphs, i.e., brigades with younger tanks did not necessarily have lower spare part costs (in terms of exchange price) per kilometer.[46] The estimates of spare part costs were adjusted for total usage, because total usage varied widely by brigade (see Appendix A), and linear regression analyses showed that total usage is the strongest predictor of the exchange price estimate, more so than the separate values of number of tanks and usage per tank. Each point in the graph represents the average age of tanks in a brigade and the exchange price estimate of spare part costs per kilometer driven for that brigade over one fiscal year between 1999 and 2002.[47] (See Appendix D for more details on the linear regression analyses.)

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[46] Although there may be a relationship between age and equipment costs by location, the small sample sizes precluded a conclusive analysis by location.

[47] The ages of the tanks fielded by a brigade were generally close. See Appendix A for descriptive statistics of the age variable.

Figure 4.2
Average Age Does Not Positively Affect M1A2 Exchange Price Estimate
When Adjusted for Total Usage
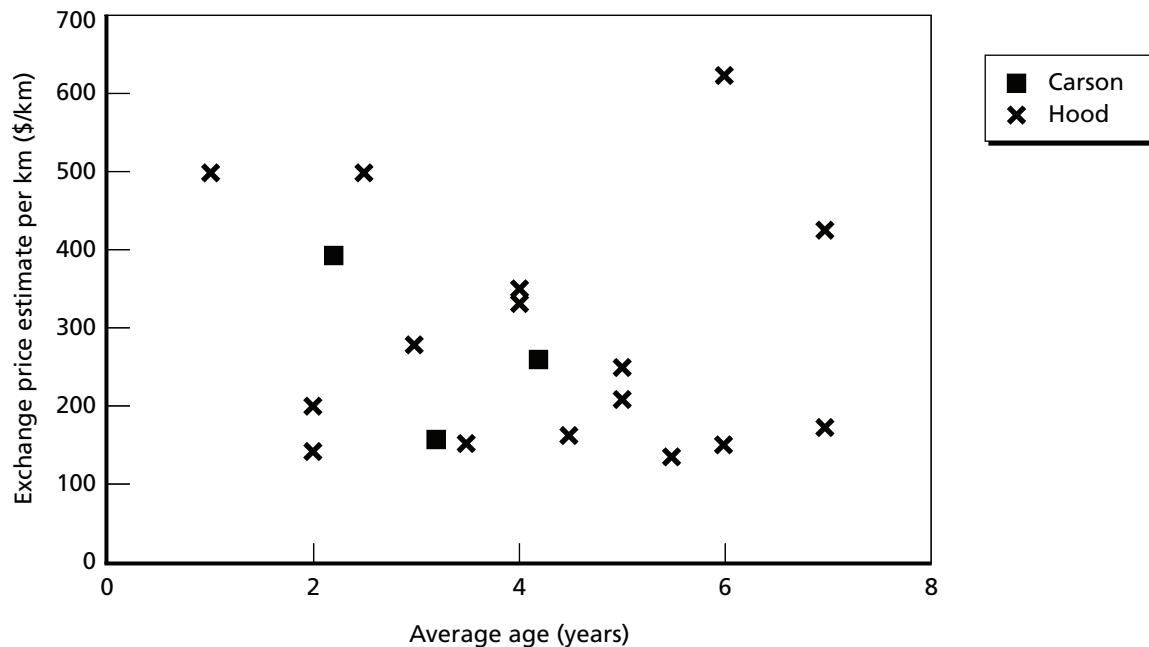
No Evidence of a Positive Age Effect on the Actual Expenditures

Despite the fact that actual expenditures reflect unit turn-in behavior, for comparison and completeness, we also include the results of our analyses on actual expenditures.

Again, our linear regression analysis shows that average age does not have a statistically significant positive relationship with estimated actual expenditures when adjusted for total usage. This can be seen in Figures 4.3 (M1A1) and 4.4 (M1A2); there is not a visible positive relationship between average age and actual expenditures adjusted for total usage, that is, brigades with younger tanks are not typically associated with lower actual expenditures.[48] (See Appendix D for more details on the linear regression analyses.)

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[48] The linear regression results actually showed that average age has a statistically significant negative relationship with actual expenditures for M1A1 spare parts. That is, the actual expenditures *decreased* as average age increased. See Appendix D for more details.

**Figure 4.3
Average Age Does Not Positively Affect M1A1 Actual Expenditures When Adjusted for Total Usage**
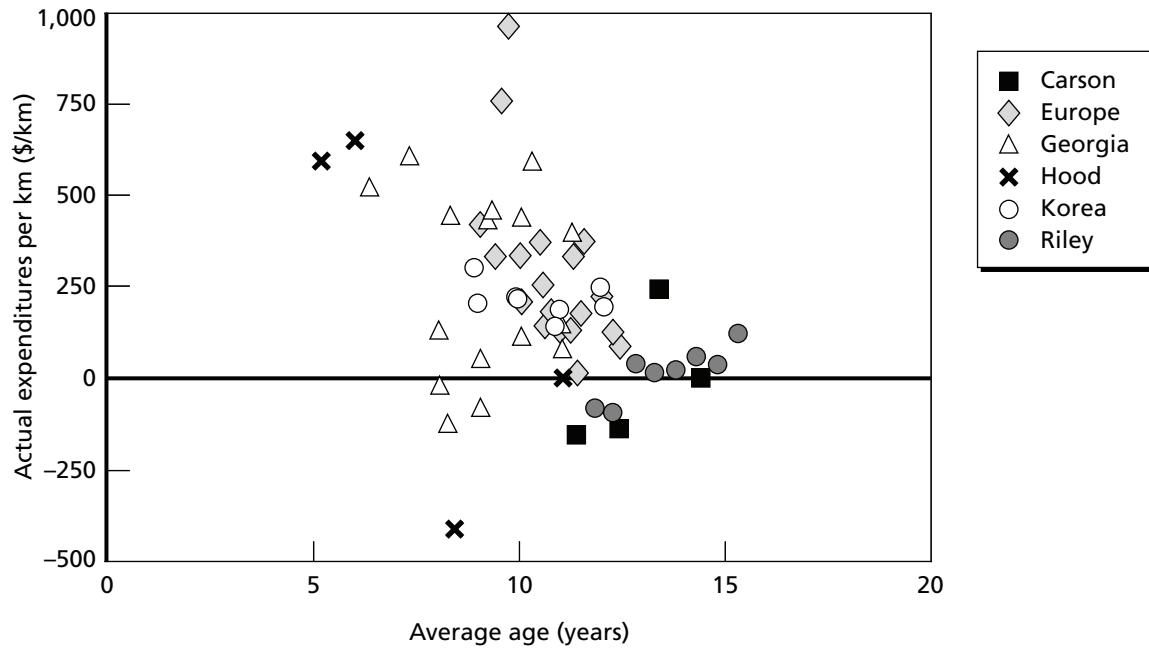
**Figure 4.4
Average Age Does Not Positively Affect M1A2 Actual Expenditures When Adjusted for Total Usage**
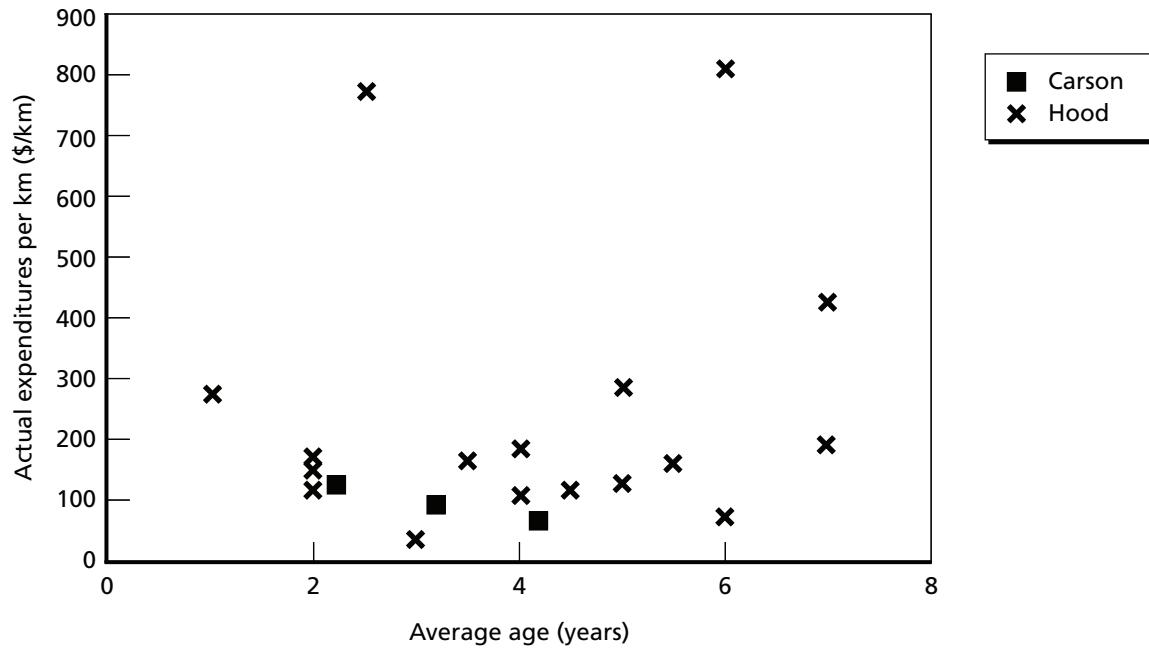
Available Spare Part Cost Data Do Not Show an Age-Cost Relationship

These results are consistent with Peltz et al. (2004) but should not be taken as evidence that age does not affect maintenance costs, only that these data do not show such a relationship. In particular, turn-in practices alone are not sufficient to obscure an age-cost relationship.

However, these results do suggest that turn-in practices have a discernible effect on the estimated relationship between age and maintenance costs: the coefficient of average age is insignificant when using the exchange price estimate, but statistically significant and negative when using actual expenditures. These findings suggest that actual expenditures should not be used to estimate a cost versus age relationship.

A complete analysis of the effects of age on maintenance costs is not possible without additional data, particularly labor data. In the next chapter, we discuss our findings and present some recommendations for change that would enable a comprehensive analysis of the effects of age on costs.

Implications and Recommendations

This chapter presents the implications and recommendations for change that would enable a more thorough analysis of the effects of age on equipment costs. We begin with a review of the data that are needed, and conclude with how these refinements might be used to improve the OMA OPTEMPO budget process.

More Refined Data Are Needed to Accurately Analyze Any Age-Cost Relationship

As first mentioned in Chapter Two, a definitive study of the effects of equipment age on operating costs cannot occur without comprehensive records linking scheduled and unscheduled maintenance costs, including labor and spare parts, to individual end items.

Currently there exist data sources that provide some but not all of the required information. The Army Materiel Systems Analysis Activity (AMSAA) Sample Data Collection links maintenance costs to individual end items. However, because the information is collected manually, the sample size and range of equipment ages are limited.

On the other hand, the Equipment Downtime Analyzer (EDA) in the Integrated Logistics Analysis Program (ILAP) tracks failure rates, downtime, and spare part costs for large numbers of individual end items, but the data do not include labor hours or information on nondeadlining failures or scheduled services.[49]

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[49] Eric Peltz et al., *Diagnosing the Army's Equipment Readiness: The Equipment Downtime Analyzer*, Santa Monica, CA: RAND Corporation, MR-1481-A, 2002.

Missing and/or inaccurate labor data are a major obstacle to a complete accounting of maintenance costs. Because military labor is a significant component of equipment costs, and because Peltz et al. (2004) suggests that increased age is associated with increased mission critical failures that drive workload, it is essential to capture the costs of labor in maintenance costs. Additional labor data that are required include: improved direct and general support labor data, and tracking of organizational labor hours, maintenance-to-maintenance actions, and nondepot contract and civilian labor, all linked to individual end items.

Improved labor data are not sufficient, however. Requisitions for parts should be linked not only to maintenance actions and individual end items, but also to the source of supply regardless of the source, e.g., bench stock, maintenance-to-maintenance transaction, local purchase, etc. Other data that are not currently well tracked at a detailed level include workarounds and deferred maintenance.

However, the data required to definitively analyze the relationship between equipment age and financial costs are extensive, and they are unlikely to be collected soon. Limited field studies, e.g., process walkthroughs, surveys, and interviews, may be an alternative first step to examine which unit behaviors obscure aging effects on maintenance costs.

The ability to link equipment costs, both labor and spare part resource consumption, to an individual end item is also important in order to utilize standard "economic useful life" models to determine cost-effective equipment replacement schedules. A history of repairs, scheduled maintenance, and overhauls performed on each individual tank and on each major component such as tank engines should also be tracked in an effort to establish the true "age" of a tank and its components.

More Refined Data May Permit Improved OMA OPTEMPO Budget Process

A complete accounting of equipment costs may enable improvements to the OMA OPTEMPO budget process. Currently, the OPTEMPO budget process assumes that a unit's demand history is an accurate record of its spare part requirements. But because a unit may not spend beyond its budget, units have

adopted certain behaviors that may obscure the effects of aging from the OPTEMPO budget process. A complete record of a unit's repair costs may permit the budget process to account for "hidden" costs, giving units access to needed purchasing power.

Further, more refined data may be used to add a trend component to the budget process. Currently, if a MACOM experiences increasing spare part demands, its OPTEMPO budget will react slowly because the budget process averages three years of demand history that is typically 3–5 years old. The addition of a trend component would allow a unit's purchasing power to react more quickly to changing demands and may reduce its need to engage in compensating behaviors. With more refined data, this trend component could be based upon time series analyses of unit data, or it could make use of statistically derived relationships between equipment age and costs.

The lack of comprehensive data that can be associated with individual end items, particularly labor data, has hampered efforts to conduct studies on the effects of age on maintenance costs. Studies using available data, such as this one, have not been able to show an effect of age on spare part costs. But this is not surprising, because Peltz et al. (2004) found that the high-cost parts that dominate M1 spare part spending do not show an age effect. Until more refined data are available or new analytic techniques are developed, conclusive studies will not be possible, making budget justifications difficult.

Summary of Data Characteristics

This appendix summarizes some of the characteristics of the data used in the analyses.

All of the variables were defined in Chapter Four, with the exception of M1A2 percent. M1A2 percent is the percentage of tanks within the brigade that are M1A2s. It is the weighted average of an indicator variable that is set to 1 when the tank is an M1A2, 0.3 when the tank is an M1A1-D,[50] and 0 when the tank is an M1A1. The indicator value is weighted according to the fraction of the total time that the tank is assigned to the brigade.

Note that because M1A1 and M1A2 tanks do not overlap in age in our dataset, and M1A2 tanks are primarily located at Fort Hood, it is not entirely possible to isolate tank variant effects from other effects such as age and location.[51]

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[50] The M1A1-D is a digitized version of the M1A1. Only the 1st Battalion, 66th Armor Regiment (1-66 AR) of the 4th Infantry Division, 1st Brigade Combat Team (4ID-1BCT) had M1A1-D tanks. These tanks were assigned an M1A2 percent value of 0.3. Sensitivity analysis conducted on this value showed that the choice of 0.3 did not affect the linear regression results for studies including M1A1-Ds. That is, the significant predictor variables remained the same and their coefficients were similar when the M1A1 percent value for M1A1-Ds was set to 0, 0.3, and 0.6.

[51] Note that the correlation coefficient between M1A2 percent and the location Hood is 0.7088; that between average age and the location Hood is –0.6771; and that between average age and M1A2 percent is –0.8304.

Note also that Fort Irwin was not included in the analysis because, as the home of the National Training Center (NTC), requisitions originating from there may have been created for the benefit of tanks based at Fort Irwin or for tanks normally based at another location. In addition, recently "recapitalized" tanks are stationed at Fort Irwin, and their inclusion might have led to skewed results, but we could have accounted for them.

Data Characteristics

Table A.1 shows descriptive statistics of the regression variables. Of note is the wide variation in usage per tank, number of tanks, and hence total brigade tank usage (total usage).

Table A.2 shows the range of values of the predictor variables used in the linear regression analyses over FYs 1999–2002 for all active brigade-sized units with M1 tanks.

Table A.1
Descriptive Statistics of Regression Variables

	Average Usage (km/tank)	Number of Tanks	Total Usage (1,000 km)	Average Age (years)	M1A2 %
Mean	976	71	69	8.7	27%
Standard deviation	424	33	46	3.6	44%
Min	102	20	6	1.0	0%
Max	1,972	124	224	15.0	100%
25th percentile	656	44	36	6.0	0%
50th percentile	967	75	53	9.6	0%
75th percentile	1,308	91	99	11.2	88%

Table A.2
**Active Brigade-Sized Units with M1 Tanks, by Post and Division/ACR, FYs 1999–2002**

Post/Theater	Division(s)/ACR	Brigades/ ACR	Average Usage (km/tank), by year	Number of Tanks, by year	Total Usage (1,000 km), by year	Average Age (years), by year	M1A2 Percent, by year
Fort Carson, CO	3rd ACR	3ACR	303–1,813	120–124	38–224	2.2–4.2	57–100%
	4th Infantry Division (4ID)	4ID-3BCT	883–1,310	44–58	43–63	11.5–14.5	0%
Europe	1st Armored Division (1AD)	1AD-1BCT	873–1,247	88–113	76–111	10.0–12.0	0%
		1AD-2BCT	272–1,170	44–56	12–52	9.5–11.5	0%
		1AD-4BCT	929–1,325	26–27	25–36	9.7–10.7	0%
	1st Infantry Division (1ID)	1ID-2BCT	751–1,426	71–73	53–101	9.4–12.4	0%
		1ID-3BCT	469–1,625	87–92	41–143	9.0–12.2	0%
Fort Stewart, GA Fort Benning, GA	3rd Infantry Division (3ID)	3ID-1BCT	285–1,127	44–58	13–50	8.2–11.2	0%
		3ID-2BCT	446–1,362	87–110	49–119	8.0–11.0	0%
		3ID-3BCT	143–1,696	43–56	6–73	8.0–11.0	0%
		3ID-AVN	436–1,724	27	12–47	6.3–9.3	0%
Fort Hood, TX	1st Cavalry Division (1CAV)	1CAV-1BCT	154–1,872	90–116	18–169	1.0–4.0	100%
		1CAV-2BCT	102–1,538	115–116	12–178	2.5–5.5	100%
		1CAV-3BCT	736–1,329	58	43–77	4.0–7.0	100%
		1CAV-4BCT	407–1,769	27–28	11–49	4.0–7.0	100%
	4th Infantry Division (4ID)	4ID-1BCT	755–1,302	76–89	57–107	8.4–9.5	0–15%
		4ID-2BCT	538–1,972	86–90	48–173	1.0–11.0	0–100%
		4ID-4BCT	608–1,404	20–28	12–39	2.0–6.0	0–100%
Korea	2nd Infantry Division (2ID)	2ID-1BCT	655–1,336	114–116	75–154	9.0–12.0	0%
		2ID-AVN	825–1,214	26–28	22–37	8.9–11.9	0%
Fort Riley, KS	1AD	1AD-3BCT	476–1,364	86–112	46–117	12.3–15.3	0%
	1ID	1ID-1BCT	605–1,141	88–116	63–101	11.9–14.8	0%

NOTE: The range of values indicates the smallest and largest values within the category for FYs 1999–2002. In particular, the "Average Age" column shows the smallest and largest values of *average* ages by brigade over FY 1999–2002, not the ages of individual tanks within the brigade.

OPTEMPO Changes

Tables A.1 and A.2 showed the wide range of usage per tank values found in the data. Figure A.1 shows the average usage per tank over time, by brigade. Over this time period, brigades have dramatically increased usage per tank, with the highest tank usage rates in FY 2001–2002. This increase may be partly due to growing congressional pressure applied in late 2001 to explain the disparity between reported OPTEMPO and the OPTEMPO objective of 800 miles (1,287.2 km).[52] Units indicated that guidance issued by GEN Shinseki in FY 2001 urged them to meet the 800-mile OPTEMPO objective. Prior to FY 2001, it had been reported that units would sometimes attempt to save on spare part costs by minimizing tank use as much as possible, such as by using heavy

Figure A.1
Average Usage per Tank Varies Greatly by Brigade and Over Time
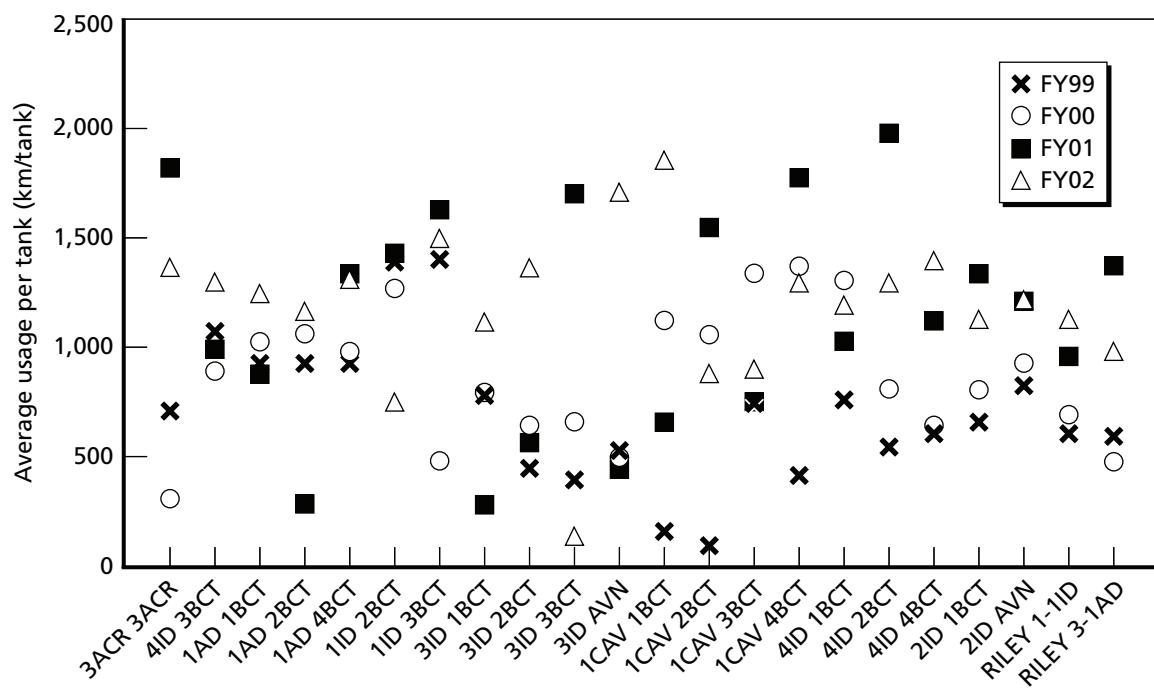
RAND *TR286-A.1*

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[52] As cited in U.S. House of Representatives, *Department of Defense Appropriations Bill, 2002 and Supplemental Appropriations*, House Report 107-298, Washington, D.C., U.S. Government Printing Office, November 19, 2001.

equipment transporters to take tanks to gunnery instead of driving them to the range. More recently, with increased pressure to drive 800 miles per tank, it has been reported that the same units are more likely to drive tanks to the range.

Tables A.1 and A.2 also showed significant variability in total usage. Figure A.2 graphically shows the wide range of total usage by brigade and over time. As was seen in Chapter Four, total usage is the strongest predictor of spare part costs—both the exchange price estimate and actual expenditures of spare part costs.

Figure A.2
Total Usage Varies Greatly by Brigade and Over Time
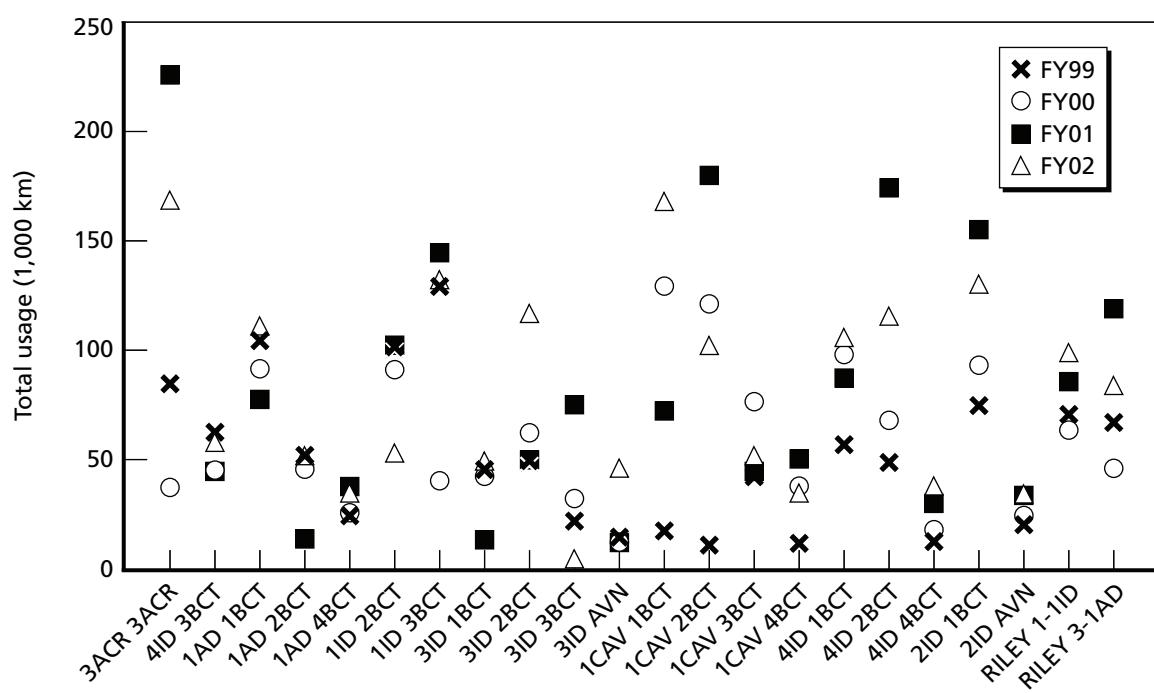
Pre-SSF Turn-In Credit Determination

This appendix explains how credit was determined for turn-ins initiated in FYs 1999–2000, prior to the implementation of SSF. Pre-SSF, the turn-in credit awarded depended on whether an item was a DLR, FLR, or consumable item; serviceable or not; and required in local inventory or not.[53] In addition, the fiscal year and first character of the materiel category (MATCAT)[54] determined the exact percentage of the full AMDF purchase price awarded.

Table B.1 shows credit rates for FY 1999, Table B.2 for FY 2000.

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[53] A DLR has Maintenance Repair (MR) code equal to D or L, or has Automatic Return Item (ARI) code equal to C, E, R, or S. An FLR does not meet the definition of a DLR and has MR equal to F or H. Any item that is not defined as a DLR or an FLR is considered a consumable item.

A serviceable item has condition code equal to A, B, C, or D. An unserviceable item has condition code equal to F or G. Items with condition code equal to H are condemned and do not receive credit.

An item is required at the local level if its advice code or return advice code (ADCDRAC) is equal to 1V. An item is not required if ADCDRAC = 1Z. Items with ADCDRAC = 1W did not receive credit.

[54] The MATCAT was taken from the January FedLog within the fiscal year in which the turn-in was initiated. Thus, a turn-in initiated in June 1999 reflected the MATCAT associated with that NIIN in the January 1999 FedLog.

Table B.1
OMA Credit Rates for FY 1999

	Credit as Percentage of Purchase Price			
	Serviceable		Unserviceable	
			Reparable Locally &	
Materiel Category	Needed	Not Needed	Needed	Not Needed
DLRs				
B (Ground Forces Support)	100	52.2	85	52.2
G (Electronics)	100	52.9	85	52.9
H (Air Materiel)	100	55.0	85	55.0
K (Tank and Automotive)	100	55.7	85	55.7
L (Missile Materiel)	100	61.5	85	61.5
M (Weapons, Chemical, and Fire Control)	100	48.2	85	48.2
U (COMSEC Materiel)	100	52.9	85	52.9
FLRs and Consumables			(FLRs only)	
C (Medical/Dental)	100	5.0	85	5.0
E (General Supplies)	100	5.0	85	5.0
F (Clothing and Textiles)	100	5.0	85	5.0
J (Ground Forces Support)	100	5.0	85	5.0
Q (Electronics)	100	5.0	85	5.0
R (Petroleum Products)	100	5.0	85	5.0
S (Subsistence)	100	100.0	—	—
T (Industrial Supplies)	100	5.0	85	5.0

*The item is "needed" if the installation's net asset position for the item is below its Retention Limit.
SOURCE: FORSCOM ALWCRPCT table, September 1998.

Table B.2
OMA Credit Rates for FY 2000

	Credit as Percentage of Purchase Price			
	Serviceable		Unserviceable	
			Reparable Locally &	
Materiel Category	Needed	Not Needed	Needed	Not Needed
DLRs				
B (Ground Forces Support)	100	63.5	80	63.5
G (Electronics)	100	53.3	80	53.3
H (Air Materiel)	100	53.3	80	53.3
K (Tank and Automotive)	100	52.9	80	52.9
L (Missile Materiel)	100	55.8	80	55.8
M (Weapons, Chemical, and Fire Control)	100	49.9	80	49.9
U (COMSEC Materiel)	100	53.3	80	53.3
FLRs and Consumables			(FLRs only)	
C (Medical/Dental)	100	5.0	80	5.0
E (General Supplies)	100	5.0	80	5.0
F (Clothing and Textiles)	100	5.0	80	5.0
J (Ground Forces Support)	100	5.0	80	5.0
Q (Electronics)	100	5.0	80	5.0
R (Petroleum Products)	100	5.0	80	5.0
S (Subsistence)	100	100.0	—	—
T (Industrial Supplies)	100	5.0	80	5.0

*The item is "needed" if the installation's net asset position for the item is below its Retention Limit.
SOURCE: FORSCOM ALWCRPCT table, September 1999.

Expensive Items Requested and Turned in to Produce Negative Actual Expenditures

This appendix contains information on two brigade-year observations: 4ID-1BCT, FY 1999; and 4ID-3BCT, FY 1999. These two brigade-year observations had actual expenditures of –$24.9 million and –$10.7 million, respectively.

To understand the reason for the large negative actual expenditures, Tables C.1 and C.2 show the requests for and turn-ins of expensive parts, by RIC, for these two brigade-year observations.[55] The items listed in Table C.1 account for –$12.9 million out of –$24.9 million in actual expenditures for 4ID-1BCT in FY 1999. Those listed in Table C.2 account for –$11.4 million out of –$10.7 million in actual expenditures for 4ID-3BCT in FY 1999.[56]

For many expensive parts, there is a greater number of turn-ins than requests, which helps to explain the large negative actual expenditures for these two brigade-year observations.[57] It is unclear why these brigades had an excess of expensive items to turn in. We do note, however, that 4ID-1BCT did turn

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[55] An item was deemed "expensive" if its AMDF unit price was greater than $50,000 according to the January 1999 FedLog.

Recall that the Army uses "prime" NIINs to identify items in supply through its logistics systems. Some items, called "related" NIINs, may be designated as interchangeable or substitutable for the "prime" NIINs. These related NIINs were not replaced by their prime NIIN for this calculation, because credit for an obsolete NIIN should not be determined by an interchangeable or substitutable NIIN.

[56] For 4ID-3BCT in FY 1999, expensive item requests and turn-ins accounted for –$11.4 million in actual expenditures. Nonexpensive item requests and turn-ins accounted for $0.7 million in actual expenditures, yielding a total of –$10.7 million in actual expenditures.

[57] There may be some windowing effect in these data: that is, because a unit may purchase a reparable in one fiscal year and turn in the unserviceable carcass in a different fiscal year, the data may be somewhat distorted. However, this windowing effect should be minimal, because requests and turn-ins are accumulated over an entire fiscal year.

in their M1A1s in exchange for M1A1-Ds in FY 2000. So it is possible they turned in M1A1 parts in anticipation of the changeover.

Table C.1
4ID-1BCT, FY 1999: Requests and Turn-ins of Expensive Items

RIC	NIIN	Nomenclature	AMDF Unit Price (FY 99 $)	Total Quantity Requested	Total Quantity Turned In
WBR	013800280	SIGHTUNIT	$64,496.47	2	0
WBR	013811842	SIGHTUNIT	$64,496.47	1	0
WGU	012168639	ENGINE,GAS TURBINE	$521,700.54	2	0
WGU	012939706	THERMAL RECEIVER WI	$95,723.63	2	0
WGW	001245387	ENGINE WITH CONTAINER	$121,543.53	1	0
WGW	001407531	TRANSMISSION AND CONTAINER	$89,440.79	1	0
WGW	012914763	THERMAL IMAGING SYSTEM	$113,367.33	1	0
WGW	012939706	THERMAL RECEIVER WI	$95,723.63	1	0
WGW	013259834	TRANSMISSION,HYDRAULIC	$190,486.86	1	0
WGW	013800280	SIGHTUNIT	$64,496.47	1	0
WGW	013885433	REMOTE CONTROL SYSTEM,AIR DEFENSE	$56,399.61	1	0
WJN	012166331	INTEGRATED SIGHT ASSEMBLY	$147,206.00	1	0
WJN	012168639	ENGINE,GAS TURBINE	$521,700.54	4	0
WJN	013800280	SIGHTUNIT	$64,496.47	5	0
WJY	000867792	TRANSMISSION AND CONTAINER	$73,476.79	1	3
WJY	001245387	ENGINE WITH CONTAINER	$121,543.53	2	9
WJY	001407531	TRANSMISSION AND CONTAINER	$89,440.79	0	7
WJY	010748947	THERMAL RECEIVER UNIT	$95,723.63	0	1
WJY	011596214	TRANSMISSION WITH CONTAINER,SHIP	$73,476.79	0	2
WJY	011662051	ENGINE AND CONTAINER	$95,564.83	0	4
WJY	012108795	TRANSMISSION,HYDRAULIC	$190,486.86	0	5
WJY	012168639	ENGINE,GAS TURBINE	$521,700.54	9	28
WJY	012718060	THERMAL RECEIVER UNIT	$95,723.63	0	7
WJY	012901290	ENGINE WITH CONTAINER	$54,003.35	1	4
WJY	012939706	THERMAL RECEIVER WI	$95,723.63	4	17
WJY	013259834	TRANSMISSION,HYDRAULIC	$190,486.86	2	9
WJY	013382703	TRANSMISSION WITH CONTAINER	$184,525.90	0	1
WJY	013765618	SIGHTUNIT	$64,496.47	0	1
WJY	013800280	SIGHTUNIT	$64,496.47	6	16
WJY	013811842	SIGHTUNIT	$64,496.47	0	2
WJY	014230929	ENGINE,DIESEL	$61,066.56	1	0
WJY	014255164	INTEGRATED SIGHT ASSEMBLY	$82,920.79	0	1

Table C.2
4ID-3BCT, FY 1999: Requests and Turn-ins of Expensive Items

RIC	NIIN	Nomenclature	Unit Price (FY 99 $)	Total Quantity Requested	Total Quantity Turned In
W97	001407531	TRANSMISSION AND CONTAINER	$89,440.79	1	0
W97	012691234	ENGINE MODULE FORWARD	$222,330.15	2	0
W97	012718060	THERMAL RECEIVER UNIT	$95,723.63	1	0
W97	012746449	TRANSMISSION WITH CONTAINER	$95,271.49	1	0
W97	012939706	THERMAL RECEIVER WI	$95,723.63	2	0
W97	013259834	TRANSMISSION,HYDRAULIC	$190,486.86	3	0
W9A	000867792	TRANSMISSION AND CONTAINER	$73,476.79	4	6
W9A	001245387	ENGINE WITH CONTAINER	$121,543.53	22	28
W9A	001407531	TRANSMISSION AND CONTAINER	$89,440.79	12	16
W9A	008949533	TRANSMISSION AND CONTAINER	$65,206.21	1	1
W9A	010748947	THERMAL RECEIVER UNIT	$95,723.63	0	2
W9A	011662051	ENGINE AND CONTAINER	$95,564.83	1	2
W9A	011787245	ENGINE MODULE REAR	$193,108.88	24	37
W9A	012029865	TRANSMISSION,WITH CONTAINER	$190,486.00	0	1
W9A	012073527	TRANSMISSION,HYDRAULIC	$242,836.09	0	1
W9A	012108795	TRANSMISSION,HYDRAULIC	$190,486.86	2	9
W9A	012166331	INTEGRATED SIGHT ASSEMBLY	$147,206.00	2	9
W9A	012168639	ENGINE,GAS TURBINE	$521,700.54	2	3
W9A	012490356	RECEIVER-TRANSMITTER,RADIO	$75,064.93	1	0
W9A	012642345	THERMAL RECEIVER WITH CONTAINER	$95,723.63	1	0
W9A	012691234	ENGINE MODULE FORWARD	$222,330.15	19	31
W9A	012718060	THERMAL RECEIVER UNIT	$95,723.63	0	4
W9A	012746449	TRANSMISSION WITH CONTAINER	$95,271.49	2	2
W9A	012901290	ENGINE WITH CONTAINER	$54,003.35	3	9
W9A	012939706	THERMAL RECEIVER WI	$95,723.63	10	9
W9A	013259834	TRANSMISSION,HYDRAULIC	$190,486.86	7	12
W9A	013382703	TRANSMISSION WITH CONTAINER	$184,525.90	13	22
W9A	013644478	THERMAL IMAGING SYSTEM	$79,138.12	6	4
W9A	013681537	ENGINE,GAS TURBINE	$521,700.54	1	2
W9A	013765618	SIGHTUNIT	$64,496.47	1	4
W9A	013765619	SIGHTUNIT	$64,496.47	0	1
W9A	013800280	SIGHTUNIT	$64,496.47	16	9
W9A	014220715	DYNAMIC REFERENCE UNIT	$117,480.00	2	2
W9A	014327915	TEST CONTROLLER	$67,570.18	1	1
W9A	014503229	KIT,RECUPERATOR TURBINE ENGINE	$73,337.80	0	3
WG2	001245387	ENGINE WITH CONTAINER	$121,543.53	2	0
WG2	013259834	TRANSMISSION,HYDRAULIC	$190,486.86	1	0
WG2	013382703	TRANSMISSION WITH CONTAINER	$184,525.90	1	0

Additional Statistical Information on Regression Analyses

This appendix contains additional statistical information on the regressions performed on the available data to determine the effects of age on the two estimates of spare part costs: the exchange price-based valuation of demands and actual expenditures. Although we prefer the exchange price estimate of spare part costs, because it does not reflect unit turn-in behavior, for comparison and completeness we also include the results of the regression analysis of the effects of equipment age on actual expenditures. This appendix describes the linear regressions performed and summarizes the findings, including a table showing the final regression models. (See Chapter Three for the definitions of the exchange price estimate and actual expenditures, and Chapter Four for definitions of the remaining variables.)

Effects of Age on Exchange Price Estimate of Spare Part Costs

The linear regression performed to assess the effects of age on the exchange price estimate of spare part costs was:

exchange price estimate = β_0 + β_1(location 2) + β_2(location 3) + β_3(location 4) + β_4(location 5) + β_5(number of tanks) + β_6(usage per tank) + β_7(total usage) + β_8(average age)

Effects of Age on Actual Expenditures of Spare Part Costs

The linear regression performed to assess the effects of age on actual expenditures of spare part costs was:

actual expenditures = β_0 + β_1(location 2) + β_2(location 3) + β_3(location 4) + β_4(location 5) + β_5(number of tanks) + β_6(usage per tank) + β_7(total usage) + β_8(average age)

The small number of regression variables enabled comparison of all possible subsets of the predictor variables. The final regression model was chosen based upon the following criteria: (1) large R^2 and adjusted R^2 values; (2) small number of predictor variables; (3) small Mallow's C_p-statistic; (4) individual predictor variable coefficients are significant at the .05 level, i.e., statistically insignificant predictors were dropped from the final models; and (5) overall regression is significant at the .05 level.[58]

Summary of Exchange Price and Actual Expenditures Studies

Table D.1 summarizes the linear regression results of the exchange price estimate and actual expenditures studies. (Chapter Four presented these results in equation form.) Each column in the table represents a different linear regression analysis. The rows (except for the last three) indicate the predictor variables included in the analysis. Each cell (except for those in the last three rows) contains the estimated parameter value associated with that row (predictor variable) and column (linear regression study); the standard error appears in parentheses below the estimated parameter value. The parameter values indicate the relationships between the predictor variables and spare part costs. Cells containing "N/A" indicate predictor variables not applicable in the regression analysis. For example, because M1A2s are located only at Forts Carson and Hood, the remaining locations are not included in the analysis.

The last three rows contain the R^2, adjusted R^2, and F-statistic values associated with each linear regression study. The R^2 value indicates the amount of variability explained by the significant predictor variables. For example, in the second column, the R^2 value of .72 indicates that about 72 percent of the variability in the M1A1 exchange price estimate can be explained by total usage

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[58] The final regression models compare favorably to models that exclude the interaction term total usage; excluding total usage does not increase the explanatory power of the model.

Also, the final regression models are a better fit than models with costs per tank as the dependent variable and location, usage per tank, and average age as the regression variables.

Table D.1
Summary of Linear Regression Analyses

Scope of Regression (Number of Observations)	Exchange Price Estimate		Actual Expenditures	
	M1A1 (N = 60)	M1A2 (N = 20)	M1A1 (N = 60)	M1A2 (N = 20)
Intercept	1.2M (1.4M)	6.1M* (2.4M)	25.6M** (7.9M)	7.2M* (3.1M)
Carson	—	—	—	—
Europe	4.4M** (1.5M)	N/A	9.3M** (3.0M)	N/A
Georgia	—	N/A	—	N/A
Hood	—	—	−12.4M* (5.9M)	—
Korea	—	N/A	—	N/A
Riley	—	N/A	—	N/A
Number of Tanks	—	—	—	—
Average Usage (km/tank)	—	—	—	—
Total Usage (km)	208*** (19)	143*** (25)	196*** (41)	75* (32)
Average Age (yr)	—	—	−2.8M** (.8M)	—
R^2	.72	.65	.48	.24
Adjusted R^2	.71	.63	.45	.19
F	74.40***	33.10***	12.90***	5.53*

   *$p < .05$
  **$p < .01$
 ***$p < .001$

NOTE: When M1A1s (M1A2s) are studied, only brigades with exclusively M1A1s (M1A2s) were included; that is, if a brigade contained both M1A1s and M1A2s, then that brigade was not included in the analyses above.

and whether the brigade is located in Europe or not. Whereas simply including additional predictor variables can increase the R^2 value, the adjusted R^2 value applies a penalty for including variables with little explanatory effect. The F-statistic indicates whether the model is significant or not.

Our analysis suggests that:

- Increased average age statistically does not lead to increased exchange price estimates or actual expenditures of spare part costs at the brigade level. Increased average age was actually associated with lower M1A1 actual expenditures in this sample.

- Location and total usage are significant predictors of spare part costs.

- Spare part costs in Europe tend to be higher than those at other locations for M1A1s.
- M1A1s appear to accrue costs at a higher rate per mile than M1A2s.
- Some costs appear to be independent of usage.

Below we look at each result in more detail:

No Statistical Evidence that Increased Average Age Leads to Increased Spare Part Costs

Our first finding is that average age does not have a statistically significant positive effect on either the exchange price estimate or actual expenditures on spare parts. That is, increased average age is not associated with increased total spare part costs in this sample. This can be seen in Table D.1 by noting that the row labeled "Average Age" contains no positive parameter values. This was also visually confirmed in Figures 4.1 through 4.4 in Chapter Four. These results also suggest that turn-in behavior alone is not sufficient to obscure an age-cost relationship.

Age Is Associated with a Negative Effect on M1A1 Actual Expenditures in this Sample

Interestingly, average age is associated with a negative effect on M1A1 actual expenditures, that is, older M1A1s tend to have lower actual expenditures in this sample. Figure D.1 depicts M1A1 actual expenditures versus average age, by location. A slight downward trend may be seen in Figure D.1, meaning that higher average ages are associated with lower M1A1 actual expenditures. Although not all locations are significant predictors, each location is depicted using a different symbol for reference.

The negative age effect is not readily apparent in Figure D.1, but it is clearer in Figures D.2, D.3a, and D.3b. These figures, which show the predicted M1A1 actual expenditures versus average age for selected combinations of location and total usage, exhibit more prominent negative slopes. The dotted lines in Figures D.3a and D.3b represent the 95 percent confidence intervals.[59]

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[59] Regression lines were not included in Figure D.1, because according to the final regression model, M1A1 actual expenditures depend on location, average age, and total usage, making it difficult to include representative regression lines for each major category.

Figure D.1
**Average Age Has a Negative Relationship with M1A1 Actual Expenditures in This Sample**
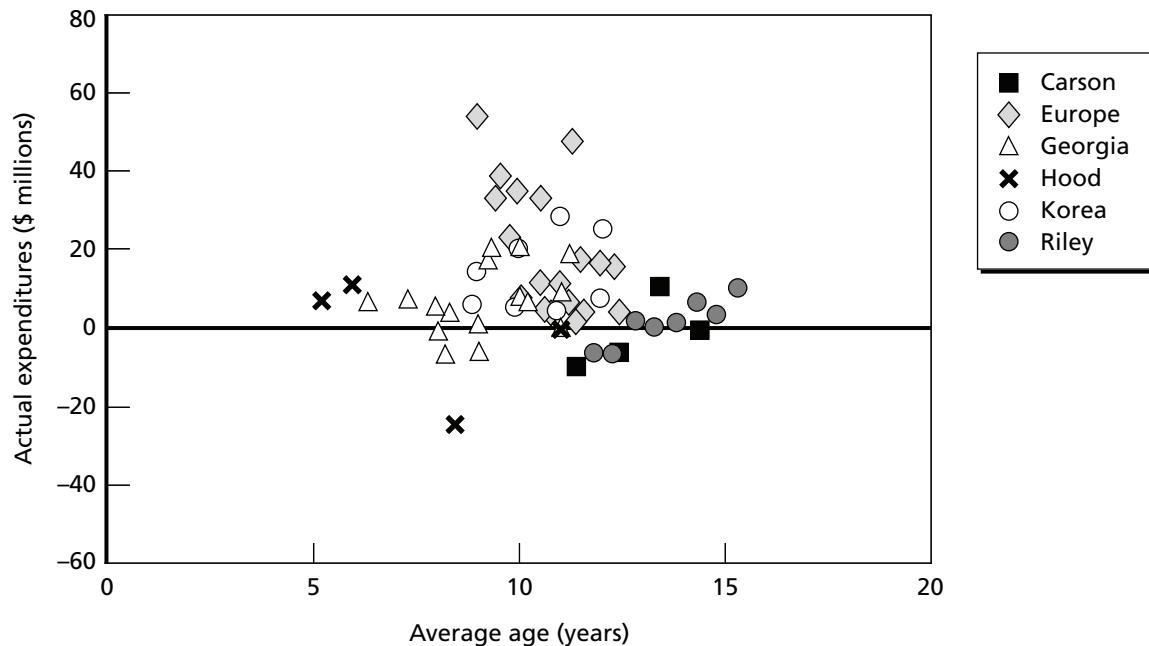
Figure D.2
Predicted M1A1 Actual Expenditures Versus Average Age, by Location-Total Usage
**(No Confidence Intervals)**
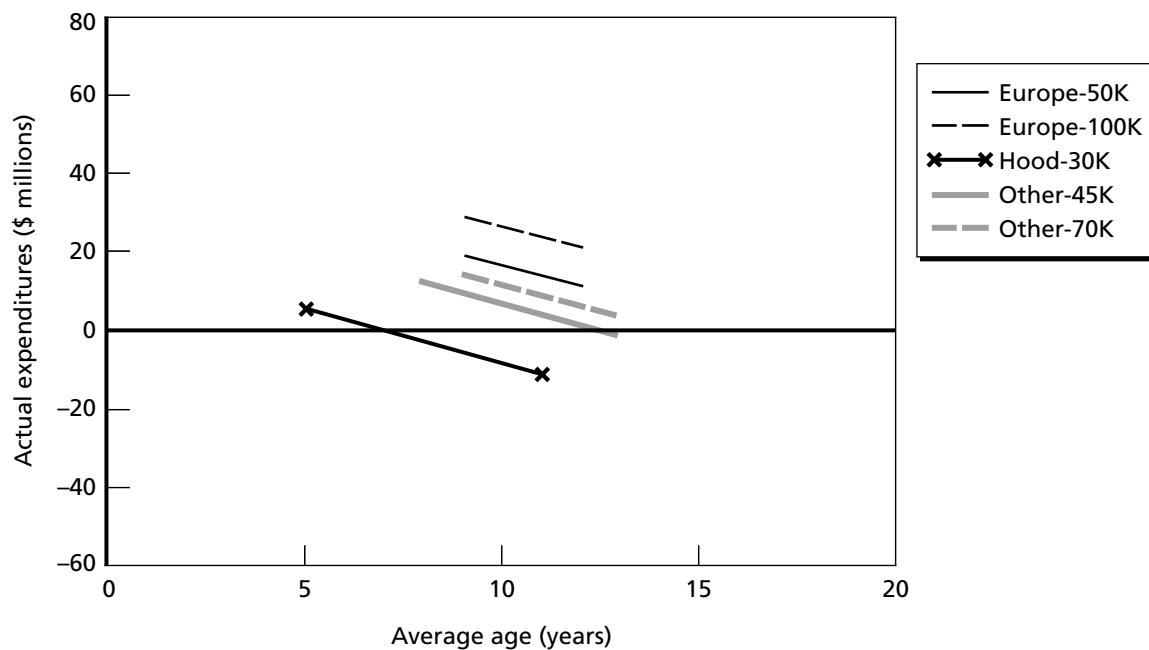
Figure D.3a
Predicted M1A1 Actual Expenditures Versus Average Age, by Location-Total Usage
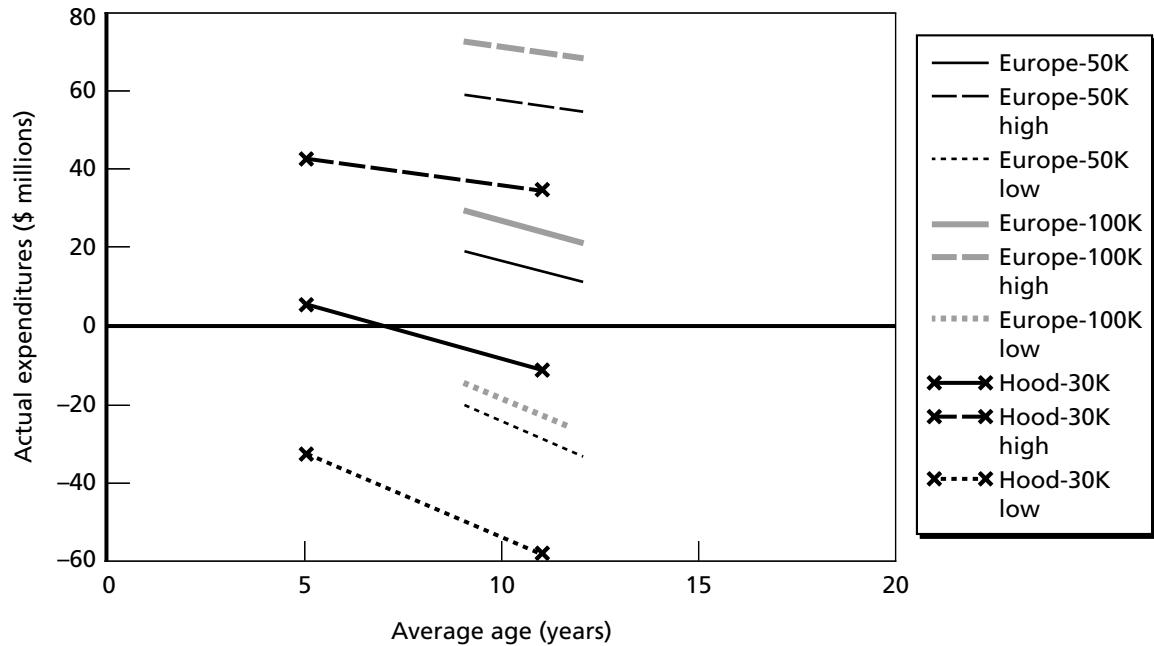
Figure D.3b
Predicted M1A1 Actual Expenditures Versus Average Age, by Location-Total Usage
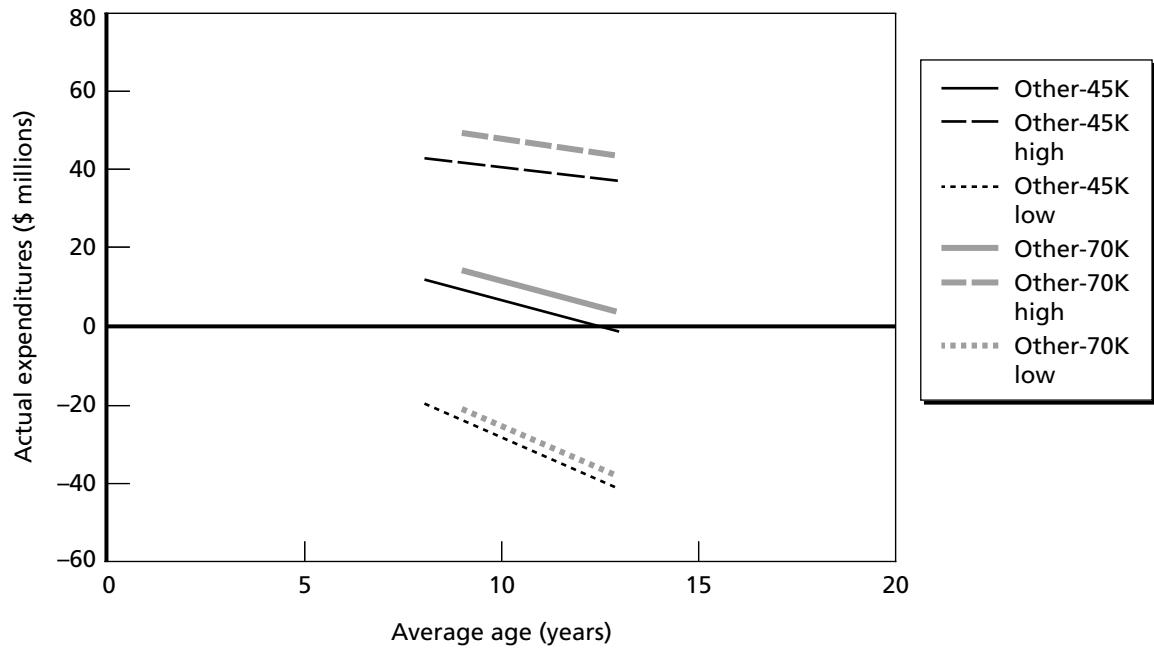
Two "Warranty" Data Points Were Excluded from Analyses

Note that two "warranty" data points (1CAV-1BCT, FY 2002; and 4ID-2BCT, FY 2001) were omitted in the M1A2 analyses listed in Table D.1. The "warranty" provided M1A2 tanks with fair wear and tear support for repair parts through the completion of New Equipment Training (NET) and for AGT 1500 tank engines up to one year after the start of NET; during this "warranty" period, worn parts were replaced free of charge.[60] When these two "warranty" data points are included in the analyses, average age has a positive effect on both the M1A2 exchange price estimate and actual expenditures of spare part costs. Given that the two "warranty" data points influence the choice of the final regression model and that there is reason to believe that their values have been artificially lowered due to Project Manager (PM) Abrams part support, these two "warranty" data points were excluded from our final analyses.

Location and Total Usage Are Significant Predictors of Spare Part Costs

The second major finding is that location and total usage are significant predictors of the exchange price estimate and actual expenditures of spare part costs. In other words, as total usage increases, so do spare part costs, with an additional expense associated with certain locations. This can be seen in Table D.1 by noting that all the parameter values in the row labeled "Total Usage" are highly significant. Some parameter values associated with the locations Europe and Hood are also statistically significant.

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[60] MAJ Brian Raftery, "Total Package Fielding for the Abrams Tank," *Army Logistics*, July–August 1999, http://www.almc.army.mil/alog/issues/JulAug99/MS433.htm (accessed September 15, 2003).

   Mr. Abimael Castro, Team Abrams Operations Officer, Fort Hood, estimates that NET for M1A2s lasts about 10 weeks. Start dates for NET at Fort Hood were as follows:

1-12 CAV	1CAV-1BCT	July 11, 2001
2-8 CAV	1CAV-1BCT	October 3, 2001
2-12 CAV	1CAV-2BCT	June 26, 2002
1-67 AR	4ID-2BCT	August 2, 2000
3-67 AR	4ID-2BCT	May 1, 2000
1-10 CAV	4ID-4BCT	January 10, 2001

M1A1s Show a Significant Relationship Between Total Usage, Location, and Spare Part Costs

The relationship between location, total usage, and spare part costs is particularly clear for M1A1s. Figures D.4 and D.6 show the strong positive relationship between total usage and the exchange price estimate and actual expenditures of spare part costs for M1A1s; the data exhibit an obvious upward trend, i.e., higher total usage is associated with higher M1A1 spare part costs. Figure D.5 shows the predicted M1A1 exchange price estimate against total usage by location. Figures D.7, D.8a, and D.8b show the predicted M1A1 actual expenditures against total usage for selected combinations of location and average age. The dotted and dashed lines in Figures D.5, D.8a, and D.8b represent the 95 percent confidence intervals. These figures, all of which depict lines with clearly positive slopes, also show the strength of the positive relationship between total usage and spare part costs for M1A1s.[61] Again, although only certain locations are significant predictors, each location is indicated using a different symbol for reference.

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[61] Regression lines were not included in Figure D.6, because according to the final regression model, M1A1 actual expenditures depend on location, average age, and total usage, making it difficult to include representative regression lines for each major category.

Figure D.4
**Total Usage Is a Significant Predictor of the M1A1 Exchange Price Valuation of Spare Part Costs**
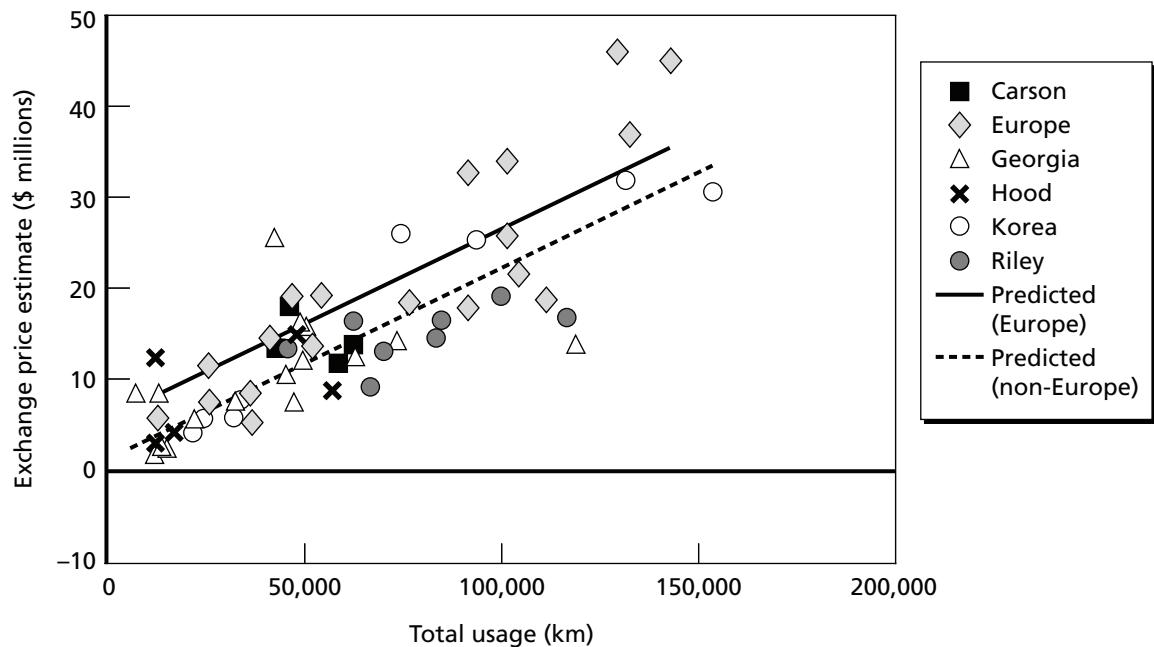
Figure D.5
**Predicted M1A1 Exchange Price Estimate Versus Total Usage, by Location**
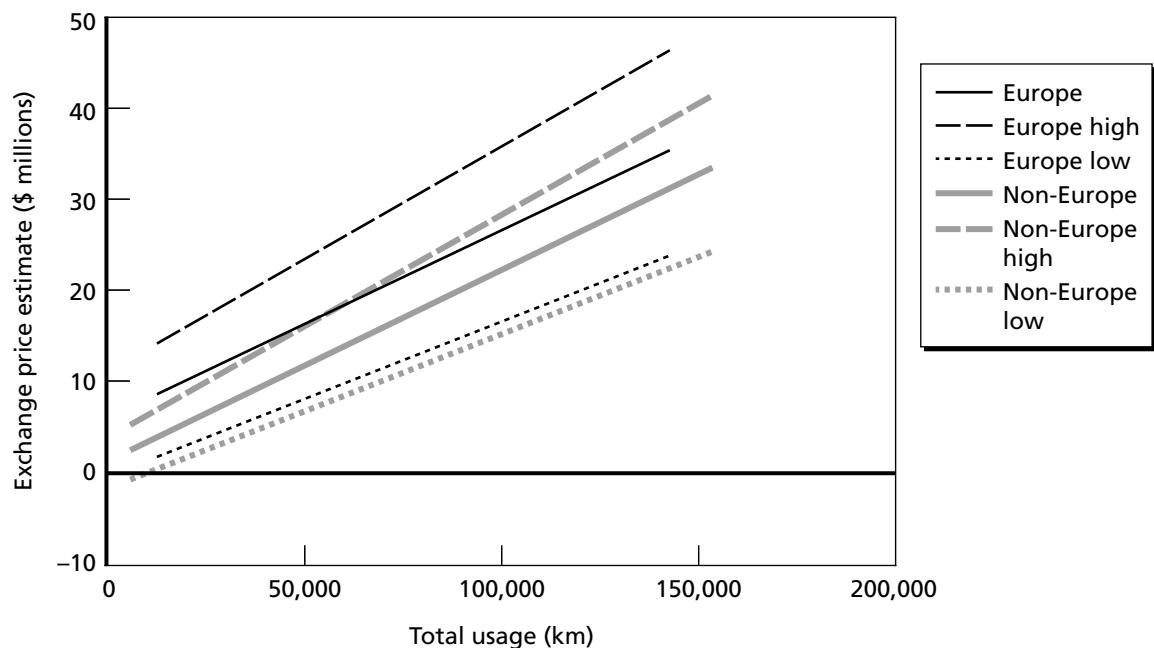
Figure D.6
Total Usage Is a Significant Predictor of M1A1 Actual Expenditures of Spare Part Costs
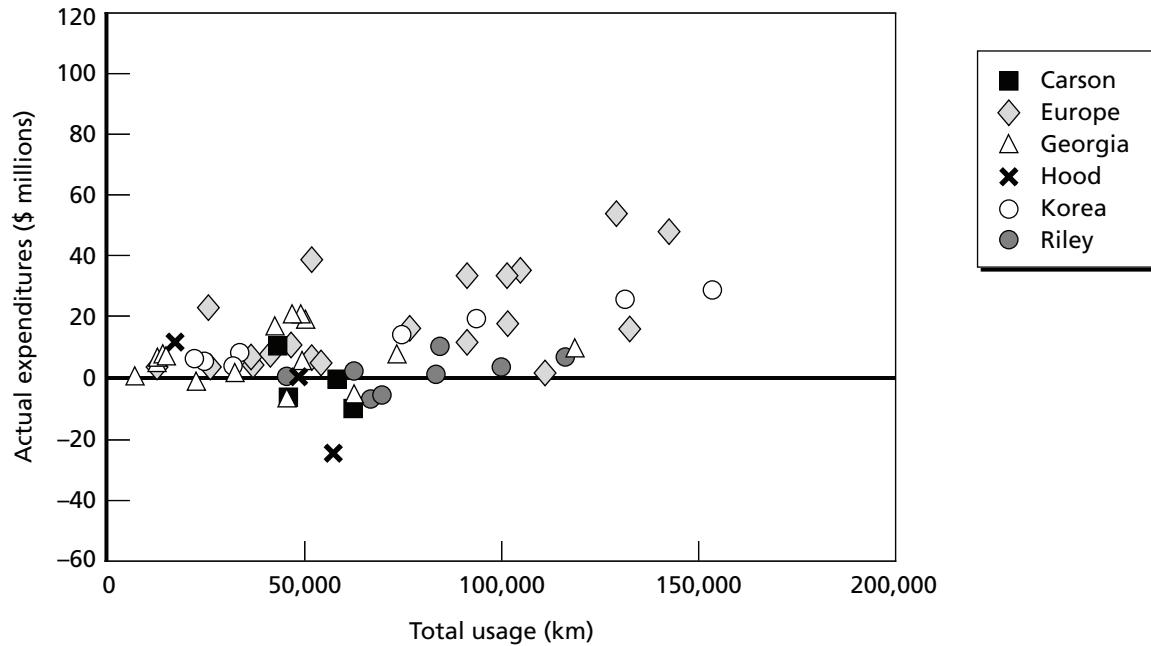
**Figure D.7**
Predicted M1A1 Actual Expenditures Versus Total Usage, by Location-Average Age
**(No Confidence Intervals)**
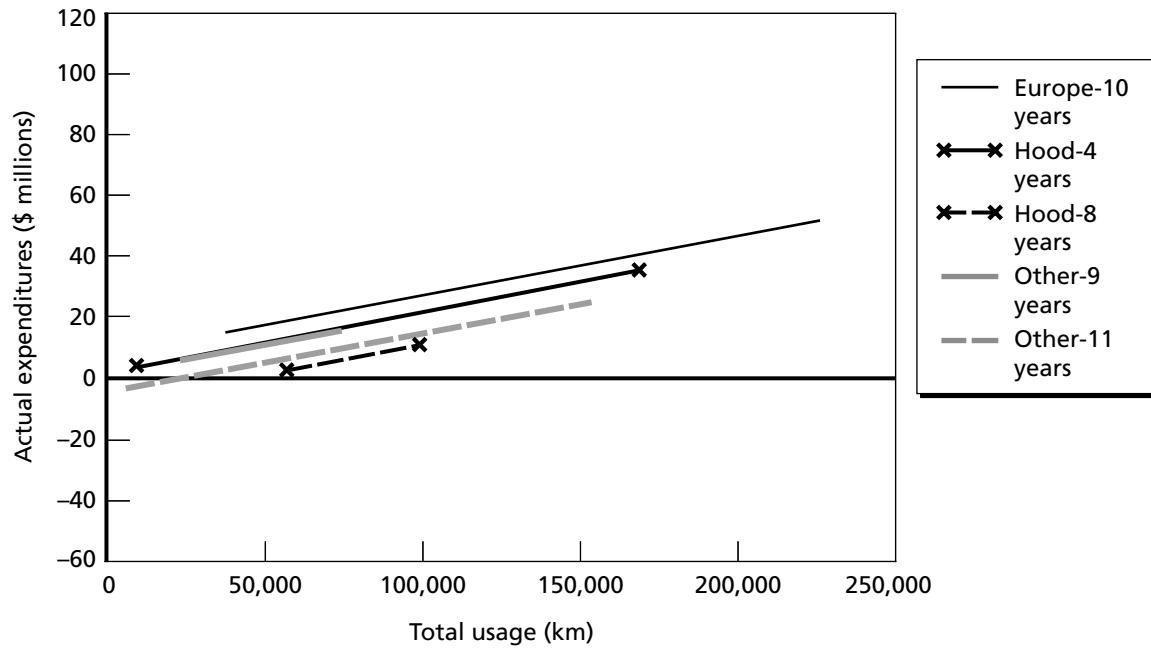
Figure D.8a
Predicted M1A1 Actual Expenditures Versus Total Usage, by Location-Average Age
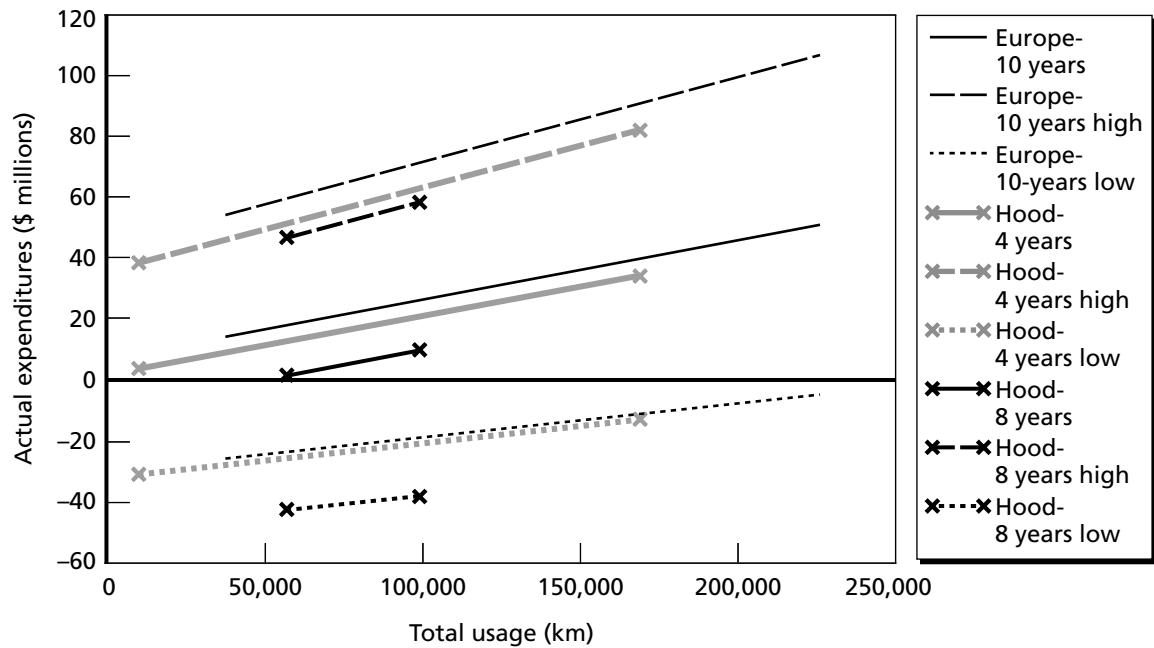
RAND *TR286-D.8a*

Figure D.8b
Predicted M1A1 Actual Expenditures Versus Total Usage, by Location-Average Age
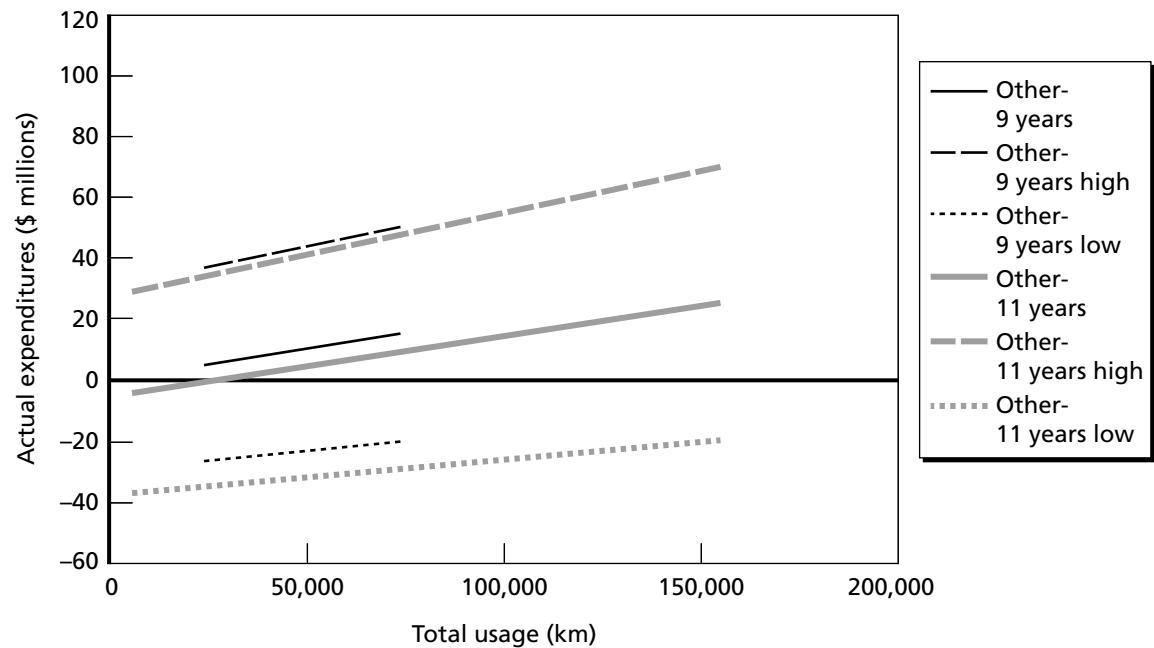
RAND *TR286-D.8b*

Total Usage Is a Significant Predictor of M1A2 Spare Part Costs

Total usage is also a significant predictor of M1A2 spare part costs. As total usage increases, so do M1A2 spare part costs. Unlike M1A1s, none of the location coefficients are statistically significant. Figures D.9 and D.11 depict the exchange price estimate and actual expenditures against total usage for M1A2s. The two "warranty" data points are displayed but not included in the regression. An upward trend can be seen in the data in these figures, that is, higher total usage is associated with higher spare part costs. Figures D.10 and D.12 show the predicted M1A2 exchange price estimate and actual expenditures against total usage, where the dotted and dashed lines represent the 95 percent confidence intervals. Again, the positive slope of the lines in these figures shows the strength of the positive relationship between total usage and spare part costs. Although location is not a significant predictor, each location is indicated using a different symbol for reference.

Figure D.9
Total Usage Is a Significant Predictor of the M1A2 Exchange Price Valuation of Spare Part Costs (Two "Warranty" Data Points Displayed But Not Included in the Regression)
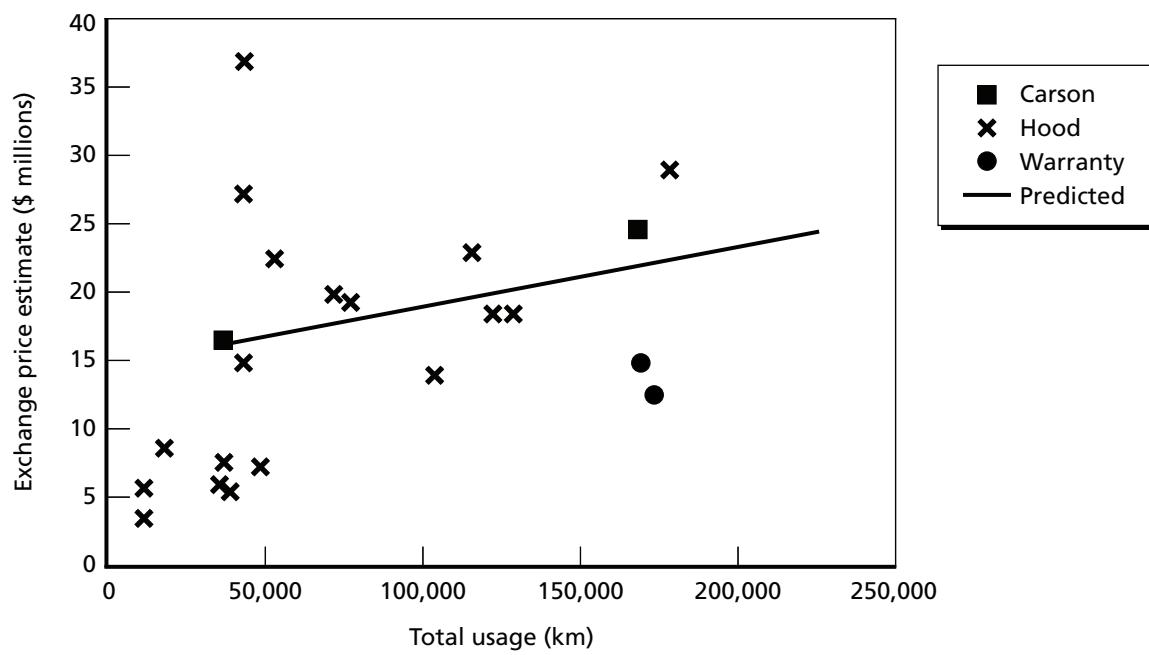
Figure D.10
Predicted M1A2 Exchange Price Estimate Versus Total Usage
**(Excludes Two "Warranty" Data Points)**
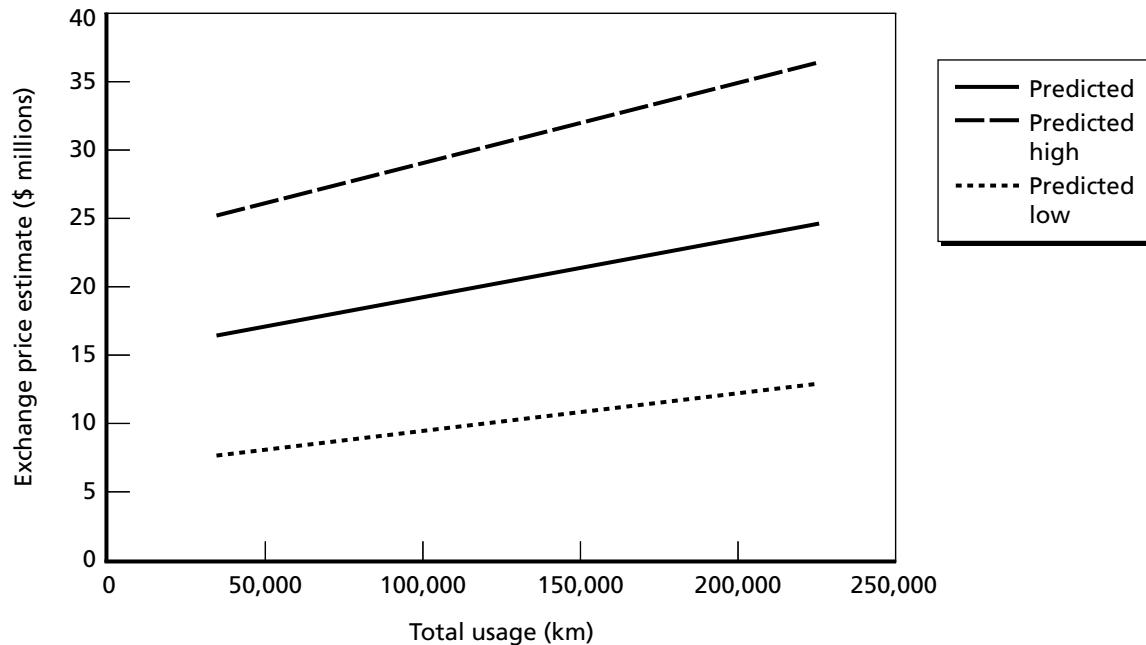
RAND *TR286-D.10*

Figure D.11
Total Usage Is a Significant Predictor of M1A2 Actual Expenditures of Spare Part Costs
(Two "Warranty" Data Points Displayed But Not Included in the Regression)
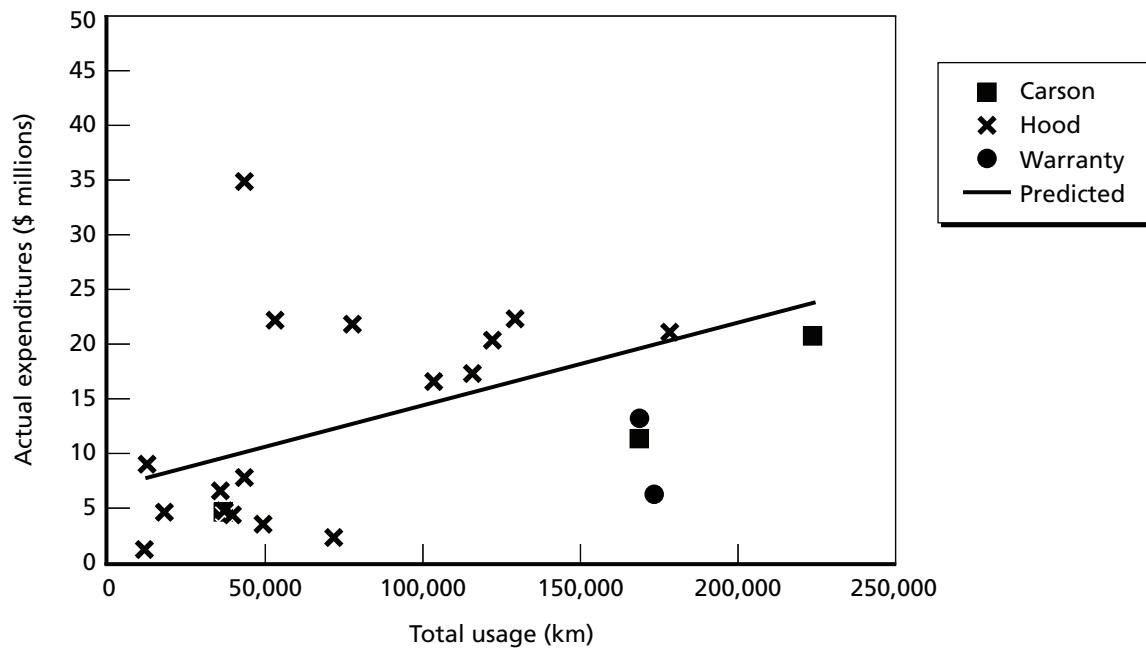
RAND *TR286-D.11*

Figure D.12
Predicted M1A2 Actual Expenditures Versus Total Usage
(Excludes Two "Warranty" Data Points)
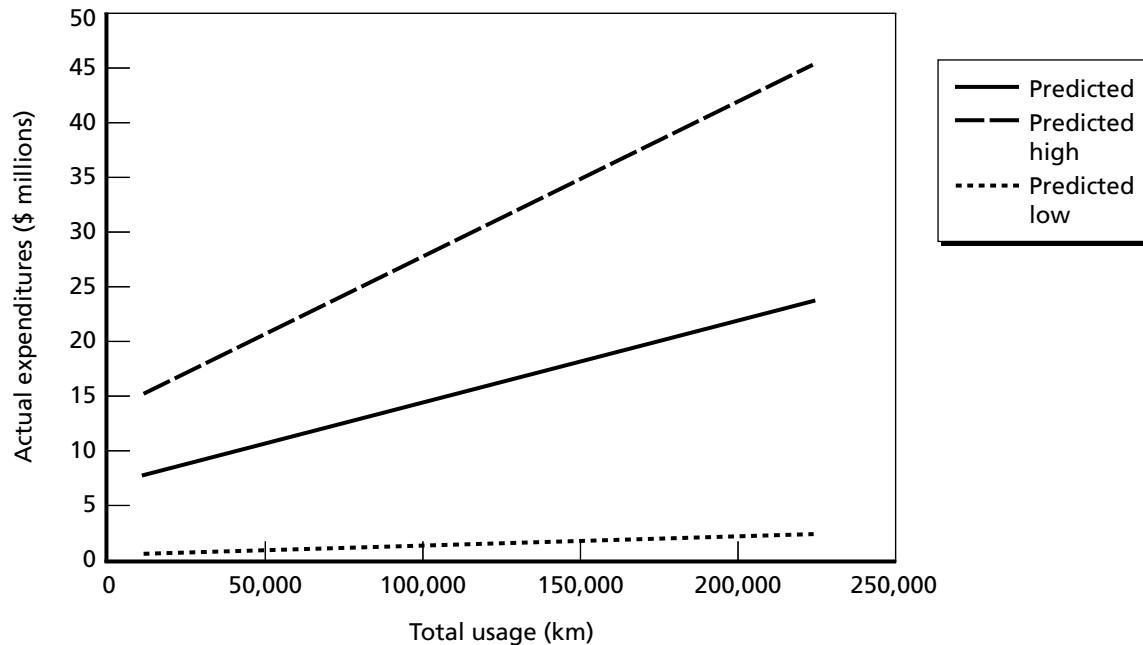
Two "Warranty" Data Points Are Not in Line with Remaining Data

The two "warranty" data points were displayed in Figures D.9 and D.11 to help explain their influential effect. (These points were not included in the analyses.) These points are not in line with the remaining data. They have large total usage yet low exchange price estimates and actual expenditures. This unusual combination helps to explain their outlier status and the fact that their inclusion alters the choice of the final regression model.

Costs in Europe Tend to Be Higher than Those at Other Locations for M1A1s

M1A1 costs tend to be higher for brigades located in Europe than for those at other locations. This can be seen in Table D.1 by noting that there are positive parameter values on the row labeled "Europe" under the M1A1 studies. These values represent the average additional expense for M1A1 brigades located in Europe. It is possible to see that costs for Europe are higher than those at other

locations by inspection of Figures D.4 and D.6: the symbol for Europe tends to occur above those for any other location. This discrepancy could be explained by differences in terrain, training practices, command policies, and maintenance practices.

M1A1s Appear to Accrue Costs at a Higher Rate per Mile than M1A2s

Another interesting finding is that M1A1s appear to accrue costs at a higher rate than M1A2s. As total usage increases, spare part costs for M1A1s increase faster than those for M1A2s. This can be observed in Table D.1 by noting that the parameter values in the row labeled "Total Usage" for M1A1s are generally higher than those for M1A2s. Because the data included only older M1A1s and newer M1A2s, it is unclear whether these differences are due to tank variant or average age.

This finding, however, is not statistically significant at the .05 level.[62] In other words, it is not possible to statistically conclude that the accrual rates are different.

There Appear to Be Some Costs Associated with Tanks Independent of Usage

The last finding is that there appear to be costs associated with tanks independent of usage or with no usage. In Table D.1, note that the parameter values in the row labeled "Intercept" are all positive, and that all but one are statistically significant. This suggests that there may be some costs driven by factors other than usage or associated with tanks with no usage. The reason for these costs is unclear. Note that the OMA budget is computed assuming no costs without usage.

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[62] In the resource consumption study, the 95 percent confidence interval for the coefficient of Total Usage for M1A1s is 170–247, while that for M1A2s is 90–195. In the actual expenditures study, the 95 percent confidence interval for the coefficient of Total Usage for M1A1s is 114–278, while that for M1A2s is 8–141.

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